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SENSORY GENERALIZATION WITH VOLUNTARY REACTIONS [1, 2]

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Theoretical contributions to the problem of learning have recently been characterized by a new series of attempts at linking the facts of conventional learning experiments with the conditioned response. The method of these systematic studies has been to use the empirical laws of the conditioned response as deductive principles in other learning situations. Maze learning (**11**, **12**), discrimination learning (**19**, **20**), and rote learning of verbal material (**13**, **14**) are some of the fields for which detailed predictions have been made by this method. As a parallel to these attempts, it seemed worth while to apply the principles of *generalization* and *differentiation* to verbal learning (**7**). If it is assumed that generalization occurs among the cue or stimulus items during the learning of verbal lists, and that blocking of the right response occurs in proportion to the strength of the tendency to generalize, then differentiation must occur as an integral part of the learning. From these, and a few other related assumptions, a number of detailed predictions can be made with reference to the learning of single lists, interference, and retroactive

[1] The writer wishes to express gratitude to Professor Clark L. Hull for encouragement and advice during the progress of this research. The experiment is one of a series of studies presented to the Faculty of the Graduate School of Yale University in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Psychology.

[2] This experiment was reported before the Eastern Branch of the American Psychological Association in 1937 (**6**).

inhibition. The only sure way of testing such a hypothesis is to make an experimental test of all the predictions which can be derived from the deductive principles or postulates. But this is a lengthy and laborious process. If certain of the underlying assumptions appear to be vulnerable and subject to relatively direct empirical test, it may be economical to begin the experimental program with an examination of them. The investigation to be reported consists of an experimental examination of an assumption underlying the application of the principle of generalization to verbal learning.

All the studies mentioned above must necessarily assume that the principles which are exploited operate not only with conditioned responses, but also with so-called voluntary reactions. Several of these laws have already been tested in connection with certain voluntary reactions (*e.g.* experimental extinction (**18**), and the importance of the temporal factor in determining direction (**21**)). It was, of course, entirely possible that the phenomenon of generalization might be peculiar in some respects to that type of learning situation from which the concept was originally derived. Although conditioned responses themselves do not appear to be confined to reflex mechanisms, there are good indications that conditioned voluntary reactions are not in every way functionally similar to conditioned involuntary reactions (**15**). We therefore desired to discover whether the phenomenon of generalization (and especially the typical gradient of generalization) would occur not only with conditioned responses, but also with reactions commonly described as voluntary ones. Accordingly, an experiment was planned with the purpose of discovering whether or not a series of stimuli known to give a gradient of generalization in a typical conditioned response situation would also do so when the response was not a reflex, but a voluntary verbal reaction. It was felt that positive results in this experiment would give some psychological justification for developing a system of the sort suggested, whereas negative results would necessarily mean abandoning the notion of relating conditioning and verbal learning by way of the concept of generalization.

A series of tactual stimuli placed at varying distances on the skin was chosen as being a stimulus dimension recognized as giving a gradient of generalization in a conditioning experiment.[3] The reaction time situation was employed, since it has been the traditional way of studying simple voluntary responses. The subject reacted verbally with a nonsense syllable. He was instructed to respond to a designated stimulus, and was given practise in so doing. Later the other stimuli were introduced to see whether they would be responded to in the same way as the practised stimulus. If there were a gradient of generalization analogous to that found with conditioned reactions, the generalized or 'false' responses should be more frequent, the nearer the stimulus to the practised one in the skin dimension.

Apparatus and Procedure

Apparatus.—Four vibratory stimuli of the type described by Bass and Hull (2) were applied to the subject's back. Each vibrator was mounted in a large rubber sponge, and the four sponges were secured in a tight cloth jacket provided with straps. Two straps extended over the subject's shoulders and two others around his chest. The vibrators were four inches apart in a straight line, and the series could be made to extend either across or up and down the subject's back. The device when worn resembled a cork life-preserver. The subject could not feel the vibrators except when they were electrically activated. The plunger of each vibrator stimulated the skin through two layers of cloth—the covering of the jacket and the subject's shirt.

Reaction time was measured by means of a voice key in circuit with a Dunlap chronoscope. The chronoscope was the regulation one sold by Stoelting, driven by a tuning fork. The voice key was the standard type which breaks a contact at the sound of the subject's voice. The preparatory intervals were regulated by a contact on a revolving drum which was stopped between trials. The drum was driven by a motor which was started at the beginning of a trial; after a variable interval, the contact was made, activating relays which simultaneously closed the vibrator circuit and started the chronoscope. The subject's reaction broke the voice-key circuit, stopping both vibrator and chronoscope. The vibrators were wired in parallel circuits and separate switch keys were mounted on the experimenter's control board, so that the appropriate one could be selected for each trial.

The subject was seated comfortably in front of a large screen, the only visible apparatus being the voice key. All other apparatus and the experimenter were concealed behind the screen.

Procedure.—The following instructions were given the subject to read at the beginning of the experiment:

> This is a reaction time experiment. That means that whenever a certain signal occurs, you are to react as quickly as you can with a particular response.

[3] Generalization gradients have been demonstrated with this stimulus dimension by Anrep (1) and by Bass and Hull (2).

> The signal will be a vibratory stimulus on the (lower, upper, right, or left) part of your back which will be demonstrated to you in a minute, and the response will consist of speaking DUT into this voice key. Whenever you feel the vibrator, say DUT immediately. The noise of the apparatus starting will serve as a ready signal so you can get prepared to respond in a hurry. You will be given some practise trials before your reaction time is recorded.
>
> You are to respond *only to the demonstrated stimulus*. Later in the experiment there will be other extraneous stimuli. These stimuli will be other vibrators, located in different places on your back. You are *not* to respond to any except the demonstrated stimulus on the —— part of your back.
>
> Experiments on reaction time show that you can go faster if you keep your mind on the response you are to make, so keep a motor attitude; that is, be prepared to say DUT the instant this vibrator stimulates you.

When the subject finished reading the instructions, the vibrator to which he was to respond was demonstrated to him. This vibrator was always at one end of the series (extreme right, extreme left, top, or bottom). Then 50 trials with the stimulus to which he had been instructed to respond (the 'practised' stimulus) were given. Reactions were taken at a rate of about one in 20 seconds. At the beginning of a trial, the experimenter started the drum (the sound of which served as a ready signal), a variable interval of from ½ to 2½ seconds intervened, the stimulus occurred, the subject responded, the drum was stopped, and the chronoscope reading taken by the experimenter.

A practise series of 50 trials was given first with the designated stimulus. Then 100 more trials were given during which the 3 'prohibited' stimuli were interspersed at random intervals among trials with the designated stimulus. Each of the 3 prohibited stimuli occurred 9 times during the 100 trials.

The order of the prohibited stimuli was varied with each subject according to a prearranged plan so that order of occurrence did not favor any one stimulus when a group of subjects was considered together. This precaution was taken in case there should be a tendency for false responses to decrease with practise.[4] A group of 9 subjects was required to balance the order. Eighteen subjects (Group I) were run with the vibrators placed vertically up and down the back (half with the practised stimulus at the top of the series, the other half with the practised stimulus at the bottom); 18 more subjects (Group II) were run with the vibrators arranged horizontally across the back (again half practised at each extreme).

The subjects were all students at Yale University and were paid for their services.

Controls.—Following the experiment proper, the subjects were given two brief series of tests, one to check on the relative intensity of the stimuli, and the other to check on their localizability. The intensity of the vibrators was controlled mechanically in so far as possible, in that the vibrators, their wiring, and mounting were identical; as a further precaution, each subject was put through a series of judgments of comparative intensity of the stimuli, in case there should be a tendency for more false responses to occur to a stimulus of stronger intensity and thereby distort the curve of frequencies.

[4] Such a tendency did occur. About 70 percent of all false responses came during the first half of these 100 trials.

Paired comparisons of the stimuli were used, and the subject was asked to give a judgment of the relative intensity. The designated or practised stimulus was used as a standard, and was paired with each other 8 times, in a random order. Data for 3 of the 4 sub-groups are presented in Table 1 (the control

TABLE 1

JUDGMENTS OF RELATIVE INTENSITY OF VIBRATORS

	Percent of Time Judged Stronger than Standard		
	Nearest Stimulus	Next Stimulus	Farthest Stimulus
Group I A	22%	49%	32%
Group I B	88%	54%	74%
Group II B	88%	86%	65%

was not thought necessary until several subjects had already been run). An examination of the percentage of time each stimulus was judged stronger in comparison with the standard shows some small differences in intensity within each group. But it is significant that the intensity differences vary in no particular direction, as the differences in frequency of response will later be shown to do. In other words, there was not the slightest tendency for the intensity variations noted to correspond with relative frequency of response to the prohibited stimuli. It may therefore be concluded that differential intensity played an insignificant part in determining the gradient of response to the prohibited stimuli.

The second control test was given to determine whether or not the four vibratory stimuli could be absolutely localized. Since the vibrators were spaced four inches apart, they were readily discriminable when one was presented for immediate comparison with another.[5] But it is often the case that two stimuli which can be easily discriminated when presented for comparison cannot be absolutely identified. Since in our experiment a stimulus was presented alone with a period of 20 seconds intervening between stimuli, something approaching an absolute localization was required, and the question arose

[5] Myers (16) gives the two-point threshold in the region of the spine as 5.4 cm when the stimuli are distributed longitudinally.

whether or not generalization was occurring as a result of the subject's inability to identify surely the designated point. Therefore, each vibrator was presented separately to the subject, and he was asked to give an absolute judgment of its spatial location by identifying the stimulus; a card bearing the numbers 1, 2, 3, and 4 in the same plane as the vibrators was placed in front of the subject to facilitate the naming response. Each vibrator was presented for identification 3 times, in a random order.

In the case of the 18 subjects who had the series of stimuli distributed *across* the back (Group II), only 1 confusion of points 0 and 1 occurred out of 108 chances (less than 1 percent).[6] No confusion of point 0 with any other point occurred. When the vibrators were distributed *up and down* the back, more errors of identification occurred. Points 0 and 1 were confused 14 times out of 108 chances (13 percent). Again, 0 was not confused with points 2 and 3. It is quite in keeping with the facts of skin sensitivity that the vibrators placed vertically should be harder to localize, since spatial thresholds are higher when stimuli are applied in a longitudinal direction on the skin than when they are applied transversely. It is clear, however, that any generalization found in Group II, at least, can hardly be due to mistaken localization of stimuli.

Results

The main question of the experiment was whether or not generalization was more apt to occur in proportion as the prohibited stimulus approximated spatially to the practised one. This question was answered by the relative frequency of response to the prohibited stimuli. These results are best presented graphically. In Fig. 1 are presented combined results for the 18 subjects who had the series of vibrators placed up and down the back. The practised stimulus is designated as 0, and the others are designated 1, 2, and 3 in order of proximity to it, regardless of whether the 0 stimulus was at top or bottom. The 0 stimulus is almost invariably

[6] The designation 0 is used to refer to the stimulated point which the subject was instructed to respond to. The numbers 1, 2, and 3 refer respectively to the vibrators nearest, next, and farthest from that point.

responded to (98 percent). False responses are made to the closest prohibited vibrator 25 percent of the time, to the next closest 14 percent of the time, and to the farthest 9 percent of the time. In general, the curve shows a continuous gradient from point 0 to point 3, in accordance with the ex-

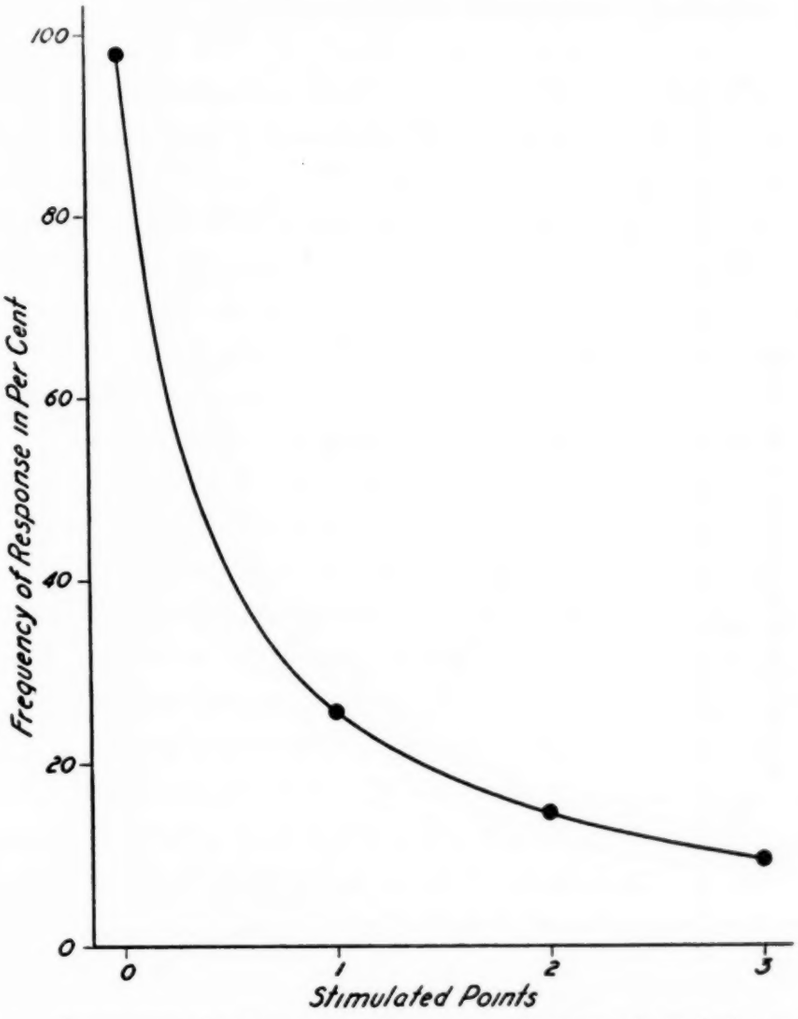

FIG. 1. Frequency of response to vibrators as a function of proximity to practised point (Group I, vibrators placed *vertically*). Frequency of response in percentage is represented on the ordinate, and stimulated points in order of proximity on the abscissa.

pectation that a process analogous to generalization of conditioned responses occurs with voluntary responses.[7] The differences between the frequencies at the four points have very satisfactory critical ratios (44.2 to 2.67), with the

[7] For a similar negatively accelerated curve of generalization in the conditioned response situation see Hovland (10).

exception of the difference between point 2 and point 3 which has a critical ratio of only 1.48.[8] The continuous downward trend, however, is unquestionable. Furthermore, when the data for the two sub-groups of 9 subjects each are plotted separately, the resulting curves are both similar to the one above, showing a continuous slope from 0 to 3.

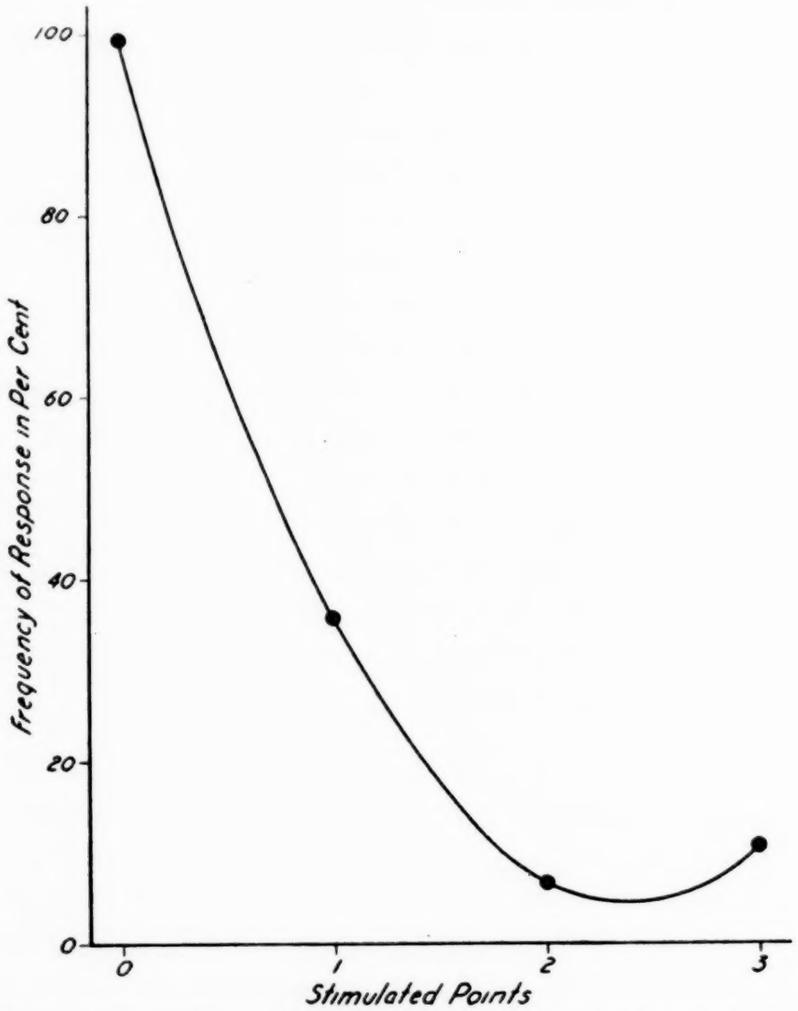

FIG. 2. Frequency of responses to vibrators as a function of proximity to practised point (Group II, vibrators placed *horizontally*).

The results for the 18 subjects who had the vibrators placed across the back are given in Fig. 2. Here the slope from point 0 to point 2 resembles closely the slope in Fig. 1, but the upturn at point 3 is not typical of the usual curve of generalization. It must be remembered, however, that the

[8] Reliabilities were calculated with the formula given by Yule (22, p. 269) for the standard error of the difference between two proportions.

vibrators here were distributed horizontally, and points 0 and 3 were consequently *symmetrical*. Perhaps the symmetrical location is responsible for the higher degree of generalization at point 3 than at point 2. Anrep (1) reports that symmetry is an effective cause of generalization; he found, in fact (with dogs as subjects), that stimulation of the point symmetrical with the 0 point was equally as effective as stimulation of the 0 point itself. The difference in this group between points 2 and 3 has a statistical reliability of only 1.16 times its standard error. But when the data for the two subgroups are plotted separately, they resemble the curve drawn from combined data, showing an upturn at 3. It seems unlikely that this is a mere chance resemblance. It is notable, also, that in Fig. 1, where there were no symmetrical points, no such upturn occurred.

It is interesting to compare percentages of generalization at point 1 in Groups I and II keeping in mind the fact that stimuli 0 and 1 were accurately localized by Group II but not invariably by Group I. It might be expected on common sense grounds that less accurate localization should accompany a greater number of false responses, but such is not the case. For Group II, the frequency at point 1 is 36 percent, while in Group I it is only 25 percent; more false responses occurred when the vibrators were easily identified. Generalization of responses, therefore, can hardly be explained by the inability of the subject to identify the correct stimulus.

A second difference is that between response to stimulation at the 0 points themselves in the two cases. Figure 1 shows a slightly lower percentage of response at this point than does Fig. 2 (98 percent as compared with 100 percent).[9] Again frequency of response was lowered when absolute localization was poorer. This fact suggests that the difficulty of discriminating points 0 and 1 in Group I induced a strong inhibitory attitude in the subjects—*i.e.*, caused them to react with greater 'caution.' If this was the case, reaction time should be increased. An examination of the times reveals that it was. Taking the first 50 practise trials as a control,

[9] Although small, the difference is statistically reliable, its critical ratio being 3.67.

and comparing with them all the trials with the o stimulus *after the prohibited stimuli had been introduced*, an average increase in latency is found in the latter case of 63 ms. in Group I, and 42 ms. in Group II. It is significant that the greater average increase in latency occurs in Group I.

The invariable increase in latency after introduction of prohibited stimuli is interesting. It is related, for one thing, to the difference always found between simple and discrimination reactions in the reaction time experiment. Furthermore, it suggests the analogous situation with Pavlov's dogs when a previously differentiated stimulus is introduced among trials with a conditioned stimulus. An inhibitory process occurs which 'spreads' or leaves an after-effect serving to depress the ensuing conditioned responses.

It should be pointed out that the possible influence of fatigue has not been controlled in the above comparison of the first 50 reactions with later reactions. It is most improbable, however, that the increase in latency is even partially due to fatigue. For one thing, practise effects would normally continue after 50 reactions and balance any fatigue; furthermore, the effects of fatigue in the reaction time experiment are very slight (see **4**, p. 46).

The reaction times were analyzed to see whether the gradient of frequency of response to the four stimuli was accompanied by a correlative gradient of speed. Superficial consideration might lead to the expectation of a negative correlation between frequency and latency, since positive evidence of such a correlation in the case of simple conditioned responses is available (**3**, **9**). But such a correlation has never been demonstrated for *generalized* responses in the conditioning situation. Furthermore, in the present situation two factors are present which cut across the expected correlation—in fact, work in opposition to it. In the first place, there is voluntary inhibition of long-latency false responses. The effect of such inhibition would presumably be to allow only the *fastest* potential responses to occur. Since the subject does not inhibit responses to the designated or practised stimulus when they are slow, no selection of fast

responses would occur for this stimulus. Simply averaging the times of all responses made to each of the four stimuli would, therefore, show an artificially *decreased* latency of response to the prohibited stimuli; whereas the superficial prediction was that latency of these responses should be greater than those to the designated stimulus, since frequency of response is lower.

Table 2 shows the average latency of response to the four points of stimulation in both groups. The average latency

TABLE 2

AVERAGE LATENCY OF RESPONSE TO THE 4 VIBRATORS IN Ms

	Vibrator 0	Vibrator 1	Vibrator 2	Vibrator 3
Group I (Vertical distribution).....	233	219	149	151
Group II (Horizontal distribution).....	170	161	106	122

at point 0 is calculated from all the responses to that stimulus *after* the introduction of the false stimuli (it will be remembered that reaction times for the preceding practise responses were shorter). The results show that the average latencies by no means increase from point 0 to point 3, as they should if a negative correlation between frequency and latency exists; on the contrary, there is a *decrease* in latency as the stimulus is displaced from the practised point. Our assumption of voluntary inhibition of long-latency false responses is therefore probably correct.

The second complicating factor is the slight tendency for the subjects of Group I to confuse points 0 and 1. It has already been pointed out that frequency of response at these points was lower than in Group II, probably because of 'caution' or a strong inhibitory attitude. It is as if the subject had to make a discrimination reaction between two confusable stimuli; and, as is well known to be the case,[10] the reaction time lengthened accordingly. The average latency at points 0 and 1 for Group I may be seen to be abnormally high in comparison with the rest of the figures.

[10] Henmon (**8**) found that the smaller the difference between two stimuli, the longer the reaction time to the difference.

The first of these two complications may possibly be eliminated by the following procedure. For each point, the times of only the fastest 6 percent of the total number of *possible* reactions may be averaged. The hypothesis is that the whole distribution of possible responses should be slightly faster, the greater the frequency of reaction produced by the

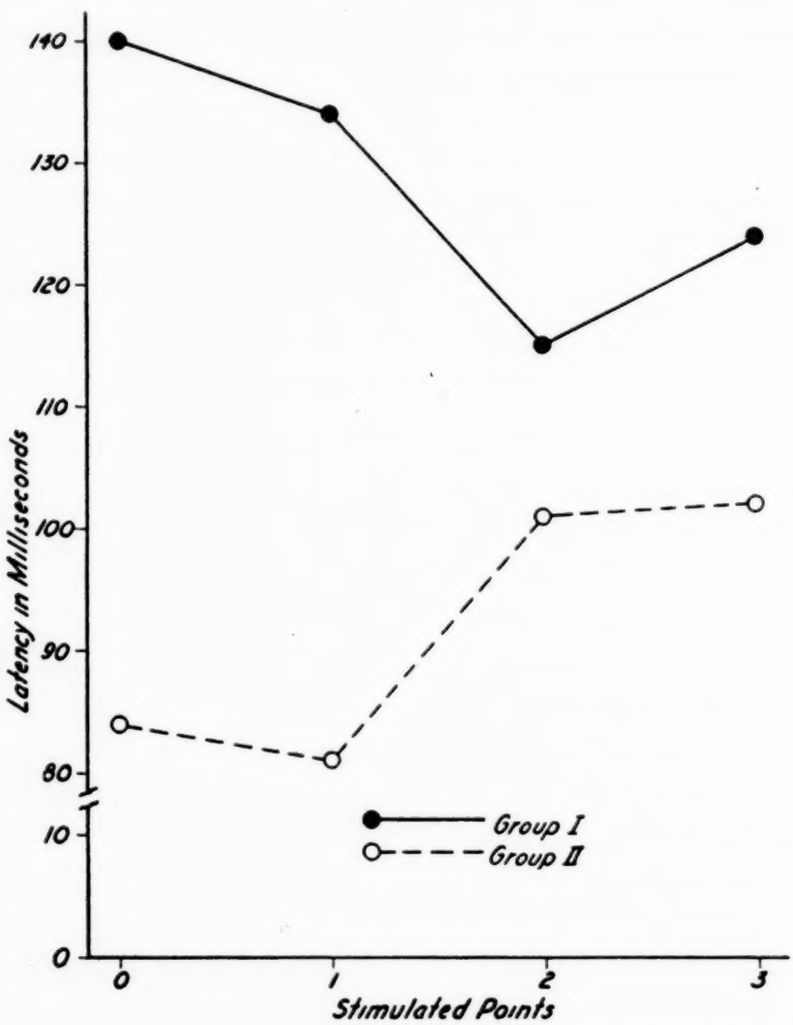

FIG. 3. Average latency of the fastest 6 percent of responses at the four stimulated points.

stimulus (or the nearer the stimulus to the designated point). By taking the top 6 percent of the potential responses, we include only reactions which were fast enough to slip by (above the threshold of voluntary inhibition), and avoid the difficulty. There is no way of avoiding the influence of the second complicating factor in presenting the results.

Figure 3 shows the curves of latency of response to the four stimuli when only the fastest 6 percent of the potential responses are included in each case. Curves for both Groups are plotted on the same axes. If there were a perfect inverse relationship between frequency and latency, the curves should show a constant upward slope. A glance at them does not indicate much tendency for an increase in latency to accompany spatial displacement from the 0 point, as does decreasing frequency. But if points 0 and 1 for Group I are discounted (for the reasons given above), there will be seen to be a rough upward trend. A perfect slope, even aside from the two discounted points, could hardly be expected considering that 6 percent of the potential reactions in the case of the three prohibited stimuli includes only 10 responses at each point. Therefore, although it cannot be concluded that speed is correlated with frequency under the present circumstances, it may be suggested that such a trend is not entirely absent when the complications introduced by difficult localization and voluntary inhibition are considered.

Discussion

Several references have already been made to the reaction time literature pointing out parallels between the present experiment and the discrimination reaction time experiment. Some other facts from this source seem to be relevant. The 'false' reaction, an event generally found but so far as we know never studied, would seem to be understandable in many cases as an example of generalization. With reference to some recent attempts to condition voluntary responses in a reaction time set-up, it has been suggested by Gibson (**5**) that what were taken to be conditioned voluntary reactions were more likely generalized reactions. The fact that generalized responses have been demonstrated to occur in a voluntary situation lends plausibility to this suggestion.

Furthermore, phenomena reported in studies of the effect of a distracting stimulus on speed of reaction to a given stimulus can be interpreted in the light of our approach. Evans (**4**) found that distraction was particularly effective when

the distracting stimulus belonged to the same sense department as the stimulus to be responded to. That is, if the distracting stimulus was an intermittent flash of light, while the designated stimulus was a flash of light of different intensity coming from a slightly different place, the increase in reaction times was greater than if the distracting stimulus had been a tone or a touch. Our data likewise show that reaction time increases significantly when other stimuli of the same dimension as the practised stimulus are introduced, especially when the new stimulus is not easily discriminated from the practised one. It may be tentatively suggested that in such situations a type of inhibition is set up comparable to the inhibitory after-effects reported by Pavlov (17, p. 125) and by Anrep (1) when a differentiated stimulus is introduced among trials with a conditioned stimulus. But such a possibility must be explored in an experiment especially designed for the purpose.

The results of this experiment have a certain bearing on the relation between conditioned and voluntary responses. In common with the experiments specifically directed at the study of this relationship, the results show both similarities and differences. Generalization and the gradient of generalization appear under both conditions. But the instructions which were necessarily introduced in the 'voluntary' situation apparently produce a set or attitude of caution which has the effect of shortening reaction times of the few responses made to the false stimuli. It is a question whether generalized responses in the conditioning situation would show an increase or a decrease. It seems possible that the latencies of generalized responses would be *longer* while the discrimination is being built up, and *shorter*, as in the present situation, when the frequency of generalized responses has been lowered by differential reinforcement. That is, establishment of differentiation would inhibit false responses in most cases; the few which occurred might be faster than normal responses, as in the present situation. Such cases might be produced by disinhibition, for instance. But investigation, rather than speculation, is obviously called for by this problem.

A new line of experimentation is suggested by the probability that false reactions to a prohibited stimulus do not occur simply because the subject cannot tell the difference between this stimulus and a designated one. Similarities of a superthreshold nature appear to play a part. The exact nature of the relationship between generalization and perceptual 'similarity' and identity is an unanswered problem, and one which should yield to a technique combining psychophysical methods and methods designed for the study of conditioned responses.

Summary

Subjects were instructed to respond verbally as quickly as possible to a designated vibratory stimulus, but not to respond in this way to other stimuli. Practise was given in responding to the designated stimulus. Later other vibratory stimuli, distributed either longitudinally or transversely on the subject's back, were introduced, to see whether generalized or 'false' responses would occur and whether they would be more frequent, the nearer the stimulus to the designated one on the skin. The following conclusions may be drawn.

1. Frequency of response to the prohibited stimuli showed a gradient of generalization analogous to the gradient found in the conditioned response experiment, when the vibrators were distributed longitudinally.

2. When the vibrators were distributed transversely, an upturn at the end of the curve of response resulted. This upturn was probably caused by the symmetrical relations of the point stimulated and the designated point.

3. Introduction of prohibited stimuli apparently produced an increase in latency of response to the designated stimulus. This increase was particularly noticeable when one of the prohibited stimuli was not easily discriminable from the designated stimulus.

4. The average latency of response to the prohibited stimuli was less than that to the designated stimulus, probably because the long-latency false responses had been inhibited.

5. When the differential effects of voluntary inhibition

were avoided, there was some indication that speed was positively correlated with frequency of response.

6. With reference to the problem of the relation between conditioned and voluntary responses, the present results suggest that similarities exist, but that differences due to the instructions introduced in the voluntary situation are to be expected.

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ANALYSIS OF A PERCEPTIBLE SERIES OF PARTIALS IN A VOCAL SOUND

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The phenomenon studied was a vocal sound of approximately constant pitch and loudness, and of short duration, during the course of which partials *three to seven inclusive* became successively prominent perceptually. The general effect of these successively distinct partials was that of a series of relatively faint tones of bell-like quality, each one heard as having a slightly percussive beginning and each one, in turn, seeming to 'stand out' from the main 'body' of the sound.[1]

The chief purpose of the investigation was to determine, insofar as possible, the relationships existing between the sound as a stimulus and the resulting auditory experience. It was of some interest to seek a plausible explanation of how the sound itself was produced by the vocalist. The general procedure was to secure information, at the outset, on the harmonic structure of the sound (especially on temporal changes in structure) and then to relate this information to what was heard. Because of difficulties in interpretation, it became necessary to devise special experiments as a means of evaluating the role played by such factors as attention and auditory masking.

A male vocalist [2] practiced until he was able to produce the sound, with its successive changes, in about 2.5 seconds, and to make the periods during which each of the perceptually

[1] The basic vocality of the sound was of indeterminate nature. Trained phoneticians, serving as observers, reported that it bore a faint resemblance to the neutral vowel in 'put' but that it could perhaps better be described in terms of deviations from a sustained 'l.' These observers further reported that there was little change in the basic quality of the sound, from beginning to end, even though the partials became successively prominent; and that whatever change did occur could not be described adequately in vocalic terms.

[2] A second vocalist also participated in the investigation; but because of the general similarity of results, this report is limited to data relating to the one case.

prominent partials was distinct of approximately equal duration. Both the loudness and the pitch of the sound were kept essentially constant throughout its course. The average fundamental frequency was about 133~, and the loudness level was in the neighborhood of 75 db.

In the recording process, during which simultaneous oscillographic and phonographic records were made, the vocalist stood in a dead room, with his lips about eight inches from the microphone. Data on the frequency response characteristics of the recording system had previously been secured and were subsequently used in correcting analytical results.

The phonograph record was used to determine the temporal features of the sound. By means of a photoelectric relay device, originally described by Fairbanks [3] and subsequently improved by Cowan, it was possible to play short segments of the record and, in this way, locate not only the portions of the sound during which each of the partials was perceptually distinct but also the points of transition. With this information in hand, it was possible to locate corresponding portions on the oscillographic tracing.

Waves selected from the oscillographic tracing were analyzed with a Henrici instrument to obtain information on the structure of the sound at various points during its course. Analysis was limited to the first ten partials because all of the partials occurring in the perceptible series were below the 10th, and because it was found that there was little energy above the frequency of the 10th. In the final computations, the relative intensities of the various partials were converted into db.

Analytical results on a fair sample of waves randomly selected from the various periods [4] showed that all of the

[3] Fairbanks, Grant. A device for copying single sounds from a phonograph record of speech or music, *Science*, 1936, **83**, 445–446.

[4] A brief explanation of certain terminology to be used should be given. The term 'period of prominence' (or 'period') refers to the portion of the sound during which a particular partial was clearly heard. Period 3, for example, refers to that portion during which the 3rd partial was heard; Period 4 to the portion during which the 4th partial was heard, and so on. Period O refers to the portion of the sound which occurred before the series of perceptible partials began. The term 'transition' is

waves from a given period had similar spectra. Consequently, it was considered desirable to secure a generalized picture of the nature of the sound in any given period by making a composite spectrum from all of the data for that period.

Composite spectra for the six periods are presented in Fig. 1. Relative intensity in db is plotted against number of partial. A study of this figure immediately reveals an interesting fact. In only one instance (during Period 3) was the partial which was heard as individually distinct the one of greatest intensity; and even in this instance of exception, the intensity of the individually perceived partial (the 3rd) exceeded that of the 2nd by less than 1 db and that of the 1st by less than 2 db. It should be noted, however, that during Periods 5, 6, and 7, the intensity of the individually perceived partial was greater than that of any other above the 3rd although the intensity of the 7th partial, during Period 7, was greater than that of the 4th by less than 1 db. During Period 4, the intensity of the 4th partial was about 8 db less than that of the 3rd, but was considerably greater than the intensities of partials five to ten.

It seems plausible to believe, in view of the data presented in Fig. 1 and particularly in view of what is known about the difficulty of 'hearing out' the partials of complex tones, that the physical nature of the sound, in and of itself, during any period of prominence, was hardly such as to explain the perceptual distinctness of the corresponding partial. This belief is borne out by another part of the investigation, to be discussed later.

Further study of the composite spectra in Fig. 1 shows that there were important differences among the various periods. During Period 3, for example, the intensity of the 3rd partial was about 10 db greater than it was during Period 0. During Period 4, the intensity of the 4th partial was 12 db greater than during Period 3 and about 8 db greater than

applied to portions of the sound which occurred between periods. Transition 3–4, for example, refers to that portion during which the 3rd partial ceased to be perceptibly prominent and the 4th became perceptibly prominent.

during succeeding periods. Similar differences may be observed for the other periods.

In order to portray more clearly the nature of period

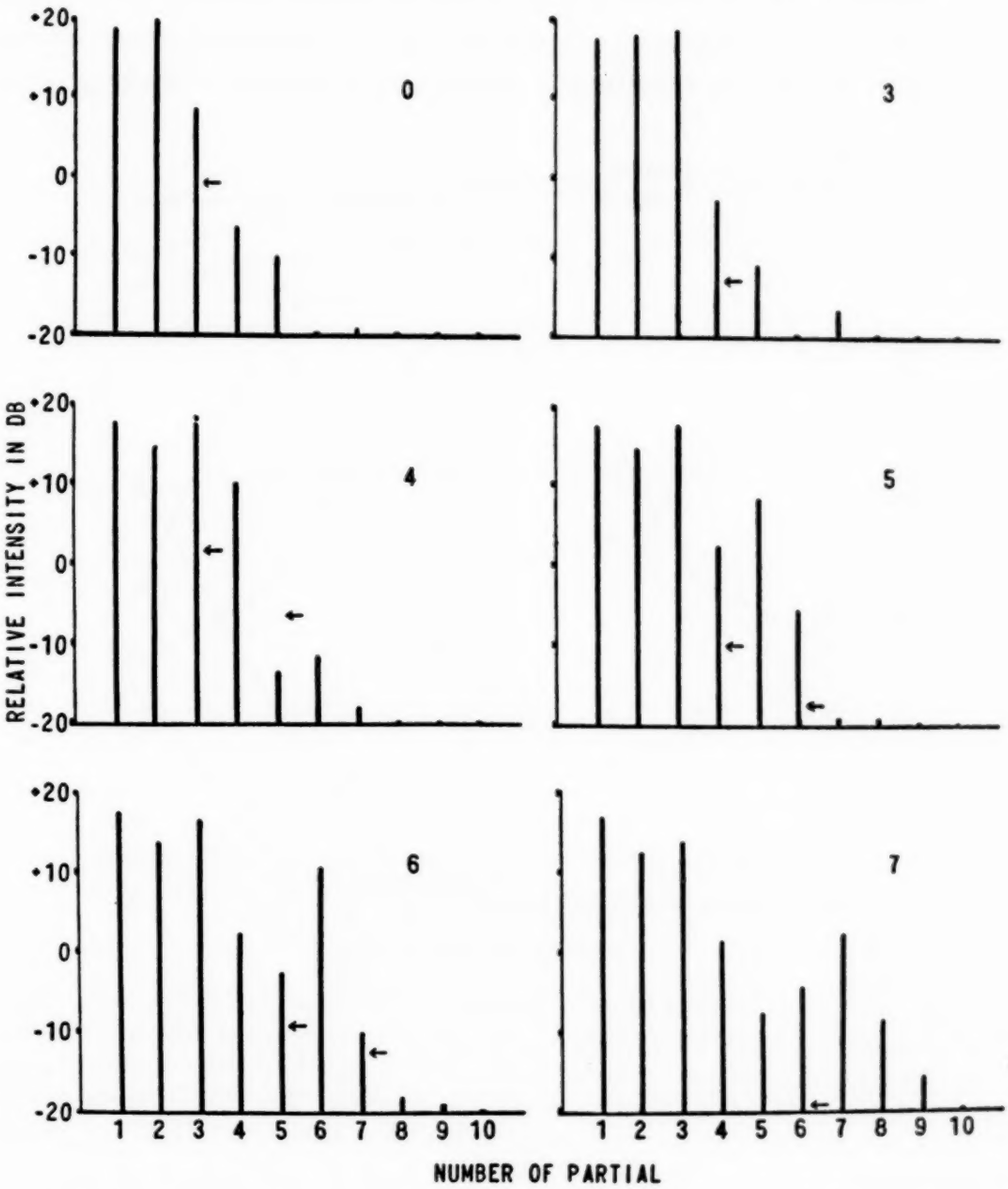

FIG. 1. Composite spectra depicting the general structure of the vocal sound during each of its six periods. The ordinate scale is arbitrary, with + 20 db corresponding roughly to the level of the complex sound as a whole. The average fundamental frequency was close to 133∼. The small arrows on the graph relate to threshold values which are dealt with in the last part of the article.

differences, the data presented in Fig. 1 were plotted in the form shown in Fig. 2. As revealed by Fig. 2, each partial was at its maximum intensity during the period when it was

individually perceived. Without exception, a partial was much more intense (14 db, on the average) during its period of prominence than during the immediately preceding period. With the exception of the 3rd, a partial was considerably more intense (11 db, on the average) during its period of prominence than during the immediately succeeding period. This second

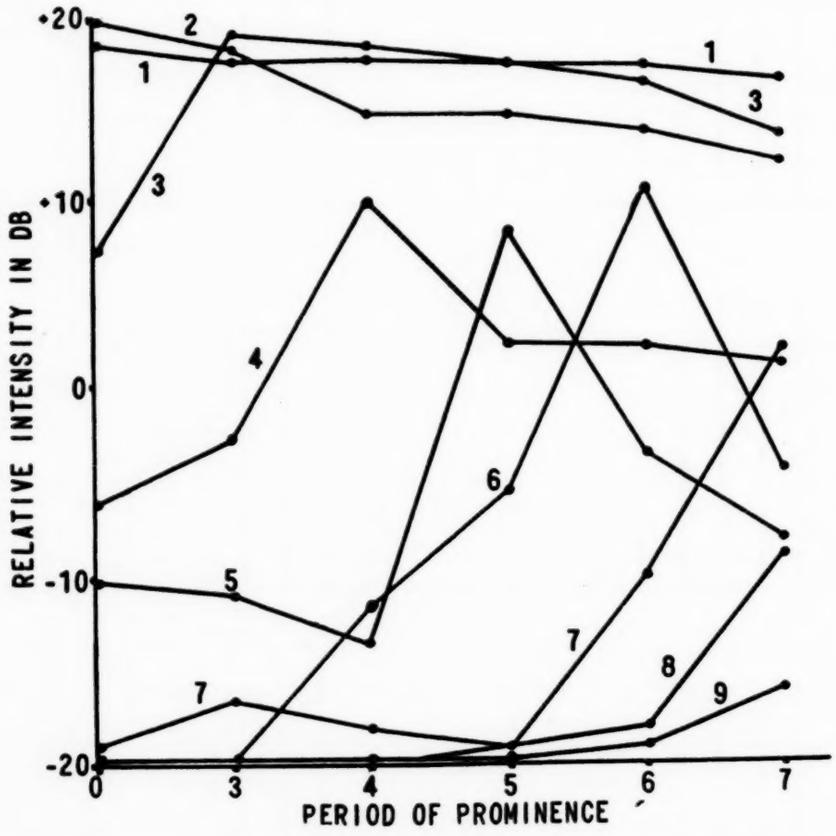

FIG. 2. Curves showing period differences in the intensity of individual partials. There is a curve, identifiable by number, for each partial up to and including the 9th. The dots represent relative intensity values for the various partials during the six periods, the periods being indicated along the abscissa. The lines connecting the dots are meaningless except as they accentuate period differences in the intensity of single partials.

generalization does not, of course, apply to the 7th partial inasmuch as Period 7 was the final portion of the sound.

The fact that a partial was at its maximum intensity during its period of prominence and was markedly less intense during both the immediately preceding and the immediately succeeding period suggested the desirability of making a detailed study of transitions. Perceptually, the change from

one prominent partial to the next seemed to occur quite abruptly; that is, each partial seemed to have a slightly percussive beginning. In relation to this percussive effect, it was found through an analysis of consecutive waves that a transition was of short duration, never lasting for more than about 0.15 second and usually for less time than that.

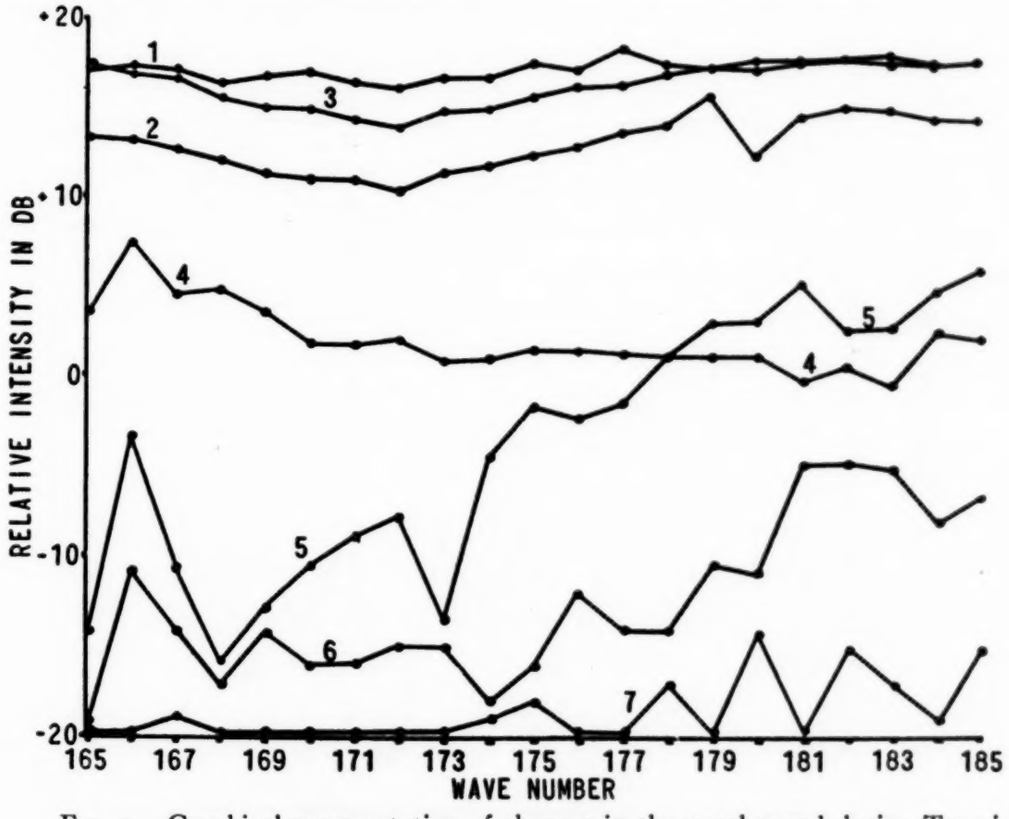

FIG. 3. Graphical representation of changes in the vocal sound during Transition 4–5. Twenty-one consecutive waves were analyzed, as indicated along the abscissa. Each of the first seven partials is represented by a curve which was formed by connecting the dots representing relative intensity values for the designated partial. Each of the twenty short segments of the abscissa may be thought of as representing about 1/133 second.

Information on Transition 4–5 is presented in Fig. 3. During Period 4, which preceded this transition, the 4th partial had an average intensity about 20 db greater than that of the 5th partial. (See Fig. 2.) During the transition, the intensity of the 4th decreased about 8 db, while that of the 5th increased approximately 18 db. At the same time, the intensity of the 6th partial also increased—by about 7 db. The other four partials represented on the graph remained

reasonably constant. Of special significance is the fact that the intensity of the 5th partial increased markedly, to become greater than that of the previously more intense 4th.

Figure 4 is a similar graph showing data for Transition 6–7. Anticipated intensity changes were found although, as the curves indicate, there was considerably more variability in crucial partials than there was in Transition 4–5. The curve

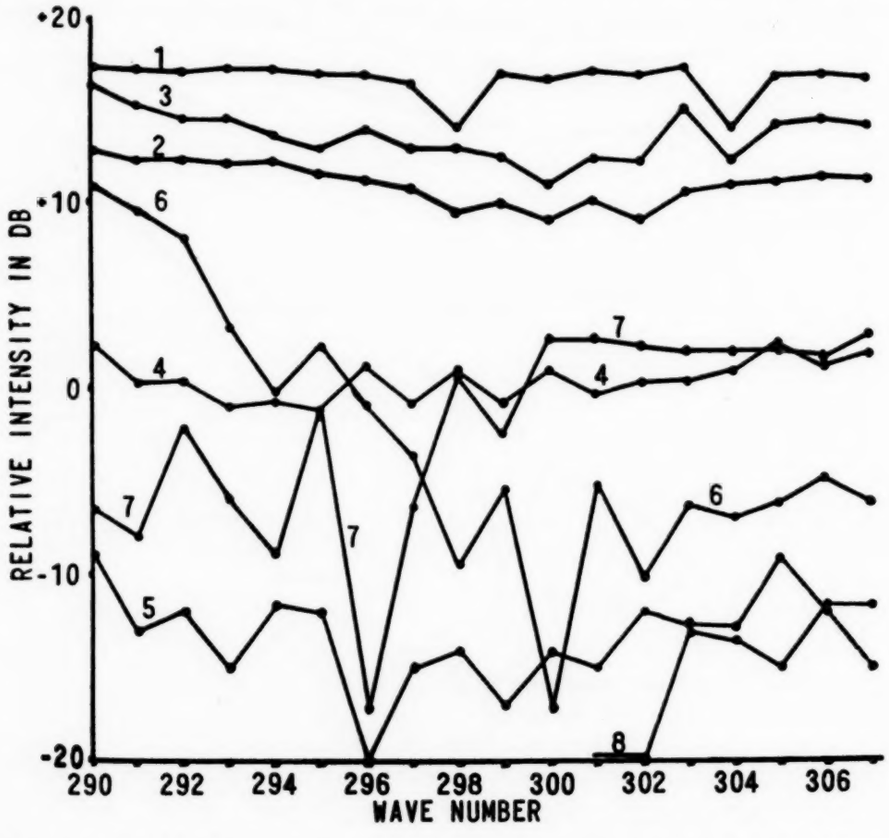

FIG. 4. Graphical representation of changes in the vocal sound during Transition 6–7. Eighteen consecutive waves were analyzed. The first eight partials are represented. The rapid and marked decrease in the intensity of the 6th partial is notable.

for the 7th partial is somewhat erratic at first, a fact which should perhaps be interpreted to mean that the vocalist had more difficulty in making this final transition than he had had in previous ones. In any event, it may be noted that, during the transition, the intensity of the 7th partial increased at least 10 db, while that of the 6th decreased more than 15 db.

The question arises as to what was operating in the production of structural changes in the sound. Logical con-

siderations, based on the present data as well as on formulations presented in a recent paper by one of the authors,[5] lead to the conclusion that resonance factors predominated. Besides, careful observations of the vocalist indicated clearly that the various partials were successively 'brought out' by means of changes in the size and shape of the vocal cavities and in the size of the mouth orifice.

It has already been suggested that the nature of the stimulus during a given period of prominence (that is, during the period alone, without the transition to it) was not such as to give rise to a perceptual distinctness of the corresponding partial. Presumably, the transitions were of crucial importance. This hypothesis was examined in the following way. The vocalist was asked to produce the sound again, but this time to prolong each period of prominence. Phonographic recordings were then made of a short segment from each of the periods, all transitions being eliminated by a switching arrangement. Each segment was of sufficient duration (about 2 seconds) to give rise to clear perception.

The segments were then presented, at random, to six observers who were asked to identify the prominent partial in each. The observers were one professional musician, two music students, and three amateur musicians, all of whom had had considerable training in careful auditory analysis. Five of the six observers were completely unable to make correct identifications or, for that matter, to designate any other single partial as individually distinct. The one observer who made correct identifications in a fair proportion of the trials was the vocalist himself. Inasmuch as he had had special opportunities to study the phenomenon and may even have based his judgments, in part, on extraneous factors, he cannot be regarded as typical. It follows, therefore, that the average well-trained observer was not able to hear the various partials as distinct and unique when they were not introduced by a transition. On the other hand, almost any observer, trained or untrained, readily perceived the partials when they occurred in the continuous series. Consequently, it is undoubtedly

[5] Lewis, Don. Vocal resonance, *J. Acous. Soc. Amer.*, 1936, **8**, 91–99.

correct to say that the transitions were of crucial importance in determining the way the sound was heard. This implies that attentional factors played a predominant role in shaping perception.

In another test, of rather incidental interest, the same segments were arranged in pairs for presentation to a group of observers. Each possible combination was presented at least twice, which allowed for a reversal in the order of the members of each pair. In addition, a number of pairs which consisted of a repetition of the same segment were included in the test. The observers were asked to judge whether the timbre of the two members of a pair was the same or different. There were relatively few errors in judgment, the data showing, in general, that the observers were able to differentiate the segments quite well on the basis of timbre.[6] This finding, when considered in relation to the inability of trained observers to make correct identifications, tends to indicate that a listener might perceive two complex tones as being different in timbre and yet be unable to designate the exact nature of the difference in terms of (say) saliency of specific partials. The implications for Ohm's Law of Acoustics are apparent.

A further aspect of the investigation remains for consideration. One wonders what role masking played in determining how the series of partials was heard. It might be presumed, in the absence of specifically applicable information on masking, that at the beginning of a given transition, the partial which was next to become prominent was below the intensity level at which it could have been heard individually at all, mainly because of masking effects. Another presumption, along the same line, would be that the partial, during the transition to its period of prominence, first rose above its masked threshold and then increased in loudness at a rapid rate. Perhaps the best example of this possibility was the change in the 5th partial which occurred in Transition 4–5. (See Fig. 3.) It might also be presumed that the

[6] Some of the paired combinations (4–5, 3–4, and 3–6, for example) were less consistently differentiated than the others. It was of some interest to note that an incorrect judgment never occurred on a pair in which the segment from Period 7 appeared.

partial which was heard distinctly during its period of prominence fell below its masked threshold during the transition to the succeeding period. The decrease in the intensity of the 6th partial in Transition 6–7 is illustrative. (See Fig. 4.)

Speculations of this type seemed somewhat reasonable but nevertheless quite inconclusive. It was decided, therefore, to make a direct experimental approach to the problem. Accordingly, the *masked absolute thresholds* [7] of the various crucial partials were measured under conditions prescribed by the spectra shown in Fig. 1. For purposes of measurement, use was made of a multiharmonic audio-frequency generator of electrostatic type.[8] The use of a calibrated Western Electric 555 receiver with the generator made it possible to deal with absolute levels of intensity.

The exact nature of the information sought may be stated quite concretely in relation to a specific example. Consider the 4th partial. During Period 3, it was not heard individually. Likewise, it was not heard individually during Period 5. Was it below its masked absolute threshold during Period 3? Was it below its m.a.t. during Period 5? In other words, did the 4th partial rise above its m.a.t. during Transition 3–4, to remain above it during Period 4, and then fall below it again during Transition 4–5? Or was it above its m.a.t. throughout? To obtain information on its m.a.t. during Period 3, the spectrum for Period 3 (see Fig. 1) was taken as a point of departure. The *standard portion* of the stimulus tone [9] was so constituted as to contain all of the partials of this spectrum *except the 4th*. It is well to bear in

[7] When a single partial of given frequency and phase is adjusted in intensity level until it is barely perceptible in the presence of other partials of known frequency, intensity, and phase, its intensity level at that point is called its masked absolute threshold for the conditions specified. See Lewis, Don, and Larsen, M. J. The measurement of timbre, *J. Acous. Soc. Amer.*, 1937, **8**, 207.

[8] The basic features of the generator have been described by Kurtz and Larsen (*Elec. Engineer.*, Sept., 1935). See also Lewis and Larsen (*op. cit.*). A more detailed description is forthcoming.

[9] The stimulus tone was produced by the generator. It had a duration of about 3 seconds, and it consisted of two portions—a *standard* portion and a *variable* portion—each about 1.5 seconds in duration. The circuit was arranged to prevent audible transient effects during the momentary shift from the standard to the variable portion, or vice versa.

mind, with respect to the particular standard here under discussion, that the 4th partial was not included in it. The fundamental frequency of the tone was essentially the same as that of the original vocal sound. The 3rd partial was given an intensity level of 70 db, with other partials having proper relative levels.[10] This setting gave the complex tone a loudness level of approximately 75 db, which agreed roughly with the loudness level of the vocal sound. The several partials, as measured across the input terminals of the 555 receiver, were in phase; that is, they were sine functions without epoch angles.[11] No attempt was made to duplicate the phase relationships of the vocal sound.

The *variable portion* of the stimulus tone was identical with the standard portion except that it contained some amount of the 4th partial. The generator is so constructed that five different variables, each with a different amount of the 4th partial and each to be presented an adequate number of times with the standard, could be set up in advance for random presentation. Sometimes the variable portion preceded, sometimes it followed, the standard portion. An observer listened monaurally and judged whether the first or second half of the stimulus tone contained the 4th partial. In this way, through the use of the psychophysical method of constant stimuli, it was possible to determine the m.a.t. of the 4th under conditions quite similar to those existing during Period 3 of the vocal sound.

In a similar manner, the m.a.t. of the 4th partial was measured under conditions governed by the spectrum for Period 5.

Threshold determinations for partials other than the 4th were likewise made, with appropriate spectra governing the structure of the stimulus tones. For example, the m.a.t.

[10] In all of the threshold measurements, the partial of maximum intensity in the particular vocal spectrum under consideration was given an intensity level of 70 db, the other partials being given proper relative levels.

[11] Doubt has been thrown on the exactness of this statement by the results of an investigation recently undertaken. It might be better to say that the partials approached an 'in-phase' relationship, with something around ± 30° being the range of possible inaccuracy.

of the 6th partial was measured, first with the spectrum for Period 5 and then with the spectrum for Period 7 governing stimulus conditions. The aim in all of the measurements was to determine, in an indirect way and to a first approximation, whether a given partial of the vocal sound was above or below its masked absolute threshold during the period preceding and the period succeeding its period of prominence.

Two observers with normal hearing participated in the experiment. The obtained thresholds for the two were averaged because of their similarity. Averaged values are presented in the third column of Table I. The approximate

TABLE I

MASKED ABSOLUTE THRESHOLDS OF PARTIALS

Partial	Period	Threshold *	Difference †
3	0	49.2	+ 9.2
3	4	52.7	+16.8
4	3	38.3	+10.0
4	5	42.5	+12.5
5	4	45.2	− 6.9
5	6	43.5	+ 5.7
6	5	35.2	+12.0
6	7	32.4	+16.5
7	6	40.3	+ 2.5

* In db above 10^{-16} watt.

† Values in this column are inferred differences (in db) between intensities of partials in the vocal sound and their masked absolute thresholds. The differences are to be regarded as only approximations because of obvious dissimilarities between the vocal sound and the generator tones. A positive value indicates that the corresponding partial was above its masked absolute threshold, a negative value that it was below.

levels of these thresholds with respect to the vocal spectra are indicated by the small arrows in Fig. 1. The values in the fourth column of the table are of principal interest. They show, for example (if they are taken as they stand), that the 4th partial was 10.0 db above its m.a.t. during Period 3 and 12.5 db above its m.a.t. during Period 5. As a further example: the 6th partial was 12.0 db above its m.a.t. during Period 5 and 16.5 db above during Period 7. With one exception (the 5th partial, which was 6.9 db below its m.a.t. during Period 4), all of the partials in the perceptible series were probably above their masked absolute thresholds during

periods both preceding and succeeding their periods of prominence. It might be concluded, therefore, that any one of the partials (except the 5th) could have been heard individually during periods proximate to its period of prominence *if attention had somehow been focused upon it.* However, a word of caution is needed.

The question arises as to how much above its m.a.t. a partial must be before it can be perceived with a reasonable degree of certainty. Obviously, a partial at its m.a.t. is *barely* audible. How much above its m.a.t. must it be before it becomes unmistakably audible? Unpublished data, secured by Lewis and Larsen, indicate that the *masked differential threshold* [12] of a partial for the first just noticeable step above its m.a.t. is ordinarily around 5 db. In other words, a partial must ordinarily be raised about 5 db above its m.a.t. before it becomes just noticeably louder than 'barely audible.' In view of this fact, it seems safe to assume that some of the partials in the vocal sound (particularly the 5th during Period 6 and the 7th during Period 6) were so low in intensity as to be only 'vaguely audible' during periods adjacent to their periods of prominence. Auditory masking is thus seen, by inference, to have played some part in determining how the series of partials was perceived.

Briefly, in summary: The data on the harmonic structure of the vocal sound, together with the results of psychophysical analysis, have seemingly furnished fairly adequate information for an interpretation of the phenomenon as heard. There seems to be adequate justification for concluding that it was the marked increase in the intensity of a partial, during the transition to its period of prominence, that attracted attention to it; and this generalization holds regardless of whether or not the partial was above its m.a.t. at the beginning of the transition. Furthermore, a partial remained at a relatively high level during its period of prominence, and was sufficiently intense to hold attention. During the succeeding transition,

[12] A masked differential threshold is defined as the amount that a partial, already at or above its m.a.t., must be raised in intensity to give rise to a just perceptible difference.

attention was drawn to a new partial because of its sudden increase in intensity. As a usual thing, this change of attention was probably facilitated by a decrease in the intensity of the previously prominent partial. The fact that each partial, in its turn, seemed to stand out from the main body of the sound may also be attributed to attentional factors. Both the rapidity and the amount of change in the intensity of a partial, during the relatively brief transition to its period of prominence, undoubtedly introduced the percussive effect accompanying its onset.

(Manuscript received August 27, 1938)

ON THE DISCRIMINATION OF MINIMAL DIFFERENCES IN WEIGHT: V. KINESTHETIC ADAPTATION FOR EXPOSURE-TIME AS VARIANT

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Immediately following exposure to a heavy weight, kinesthetic differential sensitivity is less than it was just before the exposure. Recovery sets in at once, however, and differential sensitivity increases continuously as a function of post-exposure time,—finally returning to its nominal pre-exposure value. When the exposure-weight is increased, for exposure-time as parameter, the time required for complete recovery also increases. At any moment during recovery, moreover, differential sensitivity varies inversely with the exposure-intensity. These are the principal facts established by an experiment in which exposure-time was held constant and the intensity of exposure was varied (**14**).

The experimental results published by Bronk (**2**, **3**) concerning adaptation effects in tension receptors plus the results of Field and Brücke (**5**), Gerard (**7**), and Gerard, Hill, and Zotterman (**8**) concerning adaptation effects in nerve, imply that similar results should be obtained for kinesthetic sensitivity data when time is varied and intensity is held constant.

In the present report, differential sensitivity data are presented for exposure-intensity as parameter and for exposure-time as variant. The results obtained are explained in terms which are coherent with experimentally established physiological facts.

Apparatus, Method, and General Procedure.—One exposure-intensity (W = 4000 grm.) and three exposure-times (t = 4, 64, and 256 secs.) were employed systematically to effect variations in the magnitude of kinesthetic differential sensitivity. The

observer, seated, relaxed his arms on a horizontal platform elevated to the height of his arm-pits. Both arms were flexed about 90° at the elbow. Only one arm was used during the experiment, however; presentation was unimanual (12). A passive procedure was adopted. The observer grasped the exposure-weight with his right hand in a standard manner (11), lifted the weight from the wrist as fulcrum, and then sustained it passively at a height of approximately 2.5 cm. The exposure-times were determined by metronome. Immediately following the termination of an exposure, differential sensitivity was measured at various time-intervals until it had returned to its nominal (pre-exposure) value. The standard weight at which ΔW was measured during recovery was 200 grm. This weight was grasped and lifted in essentially the same manner as the exposure-weight. The standard, however, was always sustained 3 secs. before the beginning of each measurement of ΔW. The measurements were made by the method of limits (continuous increase at a constant rate).

At specified intervals during the recovery period, the standard weight (= 200 grm.) was increased at a constant rate (= 10 grm./sec.) by the simple expedient of adding mercury from a calibrated burette to the sustained weight until the observer reported an increase in the intensity of the subjective effect, *i.e.*, of kinesthetic intensity. (For a complete description of this means of increasing the weight, see 11.) All ΔW-values were measured in grams. Throughout the recovery-period, readings were taken as nearly as possible at 30 sec. intervals. The writers served as observers.

Results.—Complete sets of measurements were secured from each observer for all three exposures. Typical sets of data are presented in Table I. The results are given in logarithmic units because for these measurements log ΔW is linearly related to log Δ-energy (14). Post-exposure times were measured in seconds.

The data for each observer are presented graphically in Fig. 1. The uppermost functions are based on the data for A. H. H.; the lower functions, for M. J. Z. The ordinates are expressed in units of log ΔW; the abscissae, in secs. The curves are intended to depict the general trend of the individual measurements in the case of each observer. The scatter of the points in the Figure is too great to be attributed to errors or variability in physical measurement and is probably due to organic variability—*i.e.*, to variations in the organism.

Three principal facts issue from these data: (*a*) ΔW decreases ($1/\Delta W$ increases) continuously after exposure and finally approximates its nominal pre-exposure value; (*b*) at any moment during recovery, ΔW varies directly ($1/\Delta W$, inversely) with the duration of the exposure; and (*c*) the duration of the recovery-interval is an increasing function of

TABLE I

LOG ΔW MEASUREMENTS FOR EACH OF TWO OBSERVERS AS A FUNCTION OF RECOVERY-TIME AND EXPOSURE-TIME

The exposure-times were: 4, 64 and 256 secs.; the exposure-weight was constant (= 4000 grm.). Each ΔW-value was measured at W = 200 grams.

Post-Exposure Time, in Secs.	Observers					
	A. H. H.			M. J. Z.		
	Log ΔW Exp. = 4 secs.	Log ΔW Exp. = 64 secs.	Log ΔW Exp. = 256 secs.	Log ΔW Exp. = 4 secs.	Log ΔW Exp. = 64 secs.	Log ΔW Exp. = 256 secs.
15	—	1.96	2.19	1.62	1.96	2.10
30	1.63	—	—	—	—	—
45	—	—	—	1.48	—	1.88
60	1.47	1.69	1.80	—	1.66	1.83
90	1.44	1.59	1.69	1.40	1.60	1.75
120	1.48	1.59	—	1.36	1.57	1.67
150	1.44	1.56	1.63	1.37	1.53	1.63
180	1.42	1.52	1.61	1.36	1.49	1.56
210	1.42	1.52	1.63		1.48	1.58
240		1.49	1.55		1.42	1.58
270		1.49	1.57		1.40	1.58
300		1.45	1.58		1.40	1.50
330		1.45	1.59		1.37	1.49
360		1.44	1.55		1.38	1.46
390		1.42	1.54		1.40	1.44
420			1.52		1.37	1.42
450			1.50		1.35	1.40
480			1.48			1.40
510			1.48			1.38
540			1.51			1.35
570			1.45			1.36

the exposure-time. These facts may be regarded as established by the results secured in the present experiments.

Theory.—The measurements secured in these experiments can be discussed from at least two points of view: descriptive and explanatory. Descriptive hypothesis is both useful and necessary. By summarizing facts, a mnemonic and pedagogical service is rendered. However, description *per se*

is not equivalent to understanding. Explanations are necessary for the understanding of experimental findings.

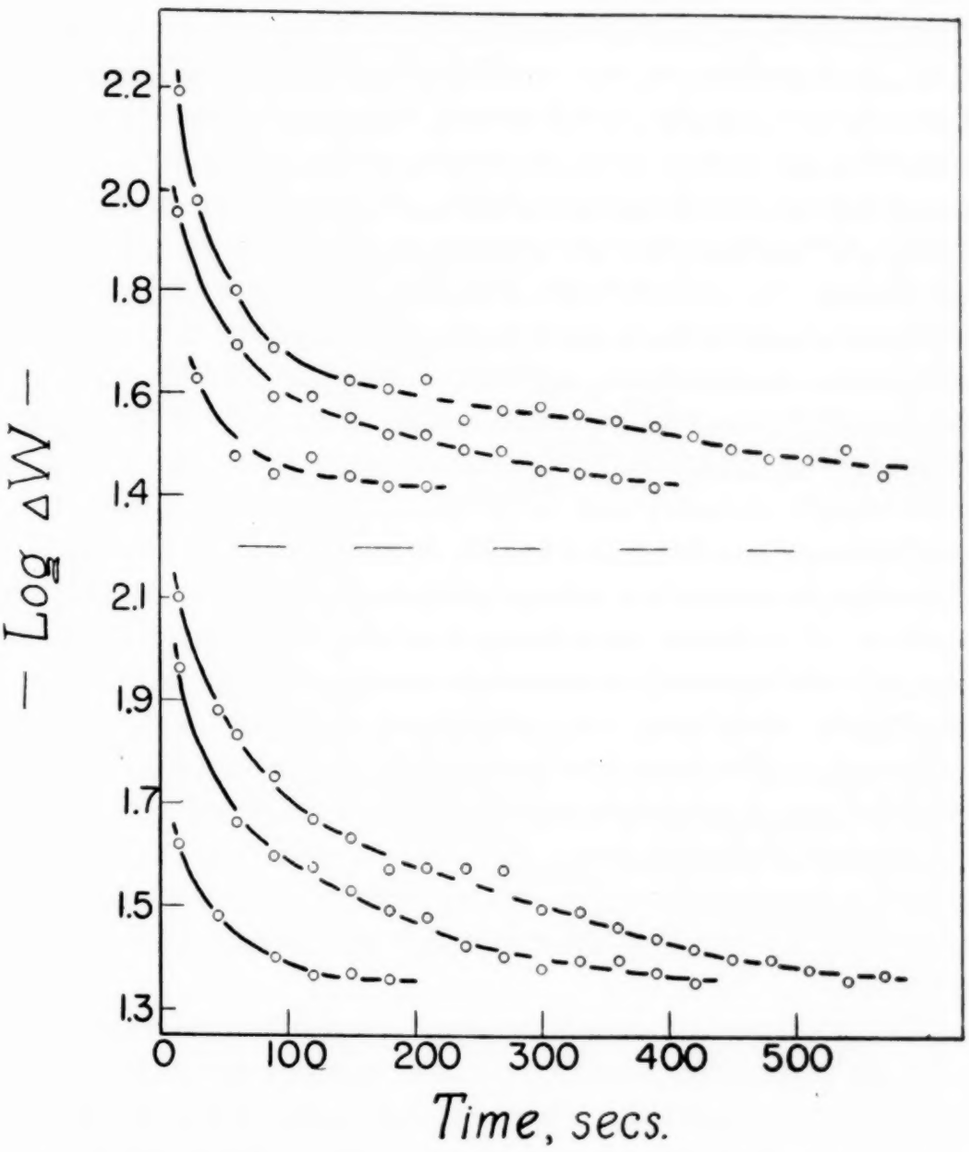

FIG. 1. Typical functions showing the behavior of log ΔW for each of two practised observers during recovery immediately following stimulation by three exposures (W = 4000 grm.; t = 4, 64 and 256 secs.). Log ΔW decreases continuously during the post-exposure interval, finally approximating its nominal pre-exposure value. At any instant during recovery, log ΔW varies directly with the time of exposure. The duration of the total recovery period also varies directly with the exposure-time. For an understanding of these facts, see text.

To contribute toward the understanding of differential sensitivity data, an explanatory theory has been advanced (9).

This theory subscribes to the idea that the variations necessary for variations in sensation are to be found in central nervous activities (*cf.* **18**). Thus the immediate causes of variations in sensory intensity are to be sought in the alteration of activities in the involved central nerve fibers. As Köhler has clearly emphasized, however, the functional activities of these central nerve cells are regulated and governed by conditions prevailing in and at the brain-center itself [1] as well as by the propagated effects of events and conditions in antecedent peripheral cells and junctions. Sufficient variation in any of these conditions may produce alterations in sensation and measurably significant variations in quantitative experimental results (*cf.* **6**, **9**). The primary or governing causes of variations in sensory data usually need to be sought in loci other than these central nerve cells.

On the other hand, according to our principal postulate, a variation in sensation *always* means a variation in the disposition of nervous excitation, and for the general explanation of differential sensitivity results in terms of these immediate activities, two additional hypotheses have been employed. The first has been called the principle of neural availability—a principle which seems more nearly to deserve the rank of observed fact. The second concept, the constant quantity hypothesis, may yet achieve the status of a principle—but for the present it is employed simply as a working hypothesis.

The availability principle observes differential sensitivity to be an increasing function of the number of central nerve impulses per unit time available for stimulation by a unit amount of the stimulus (*cf.* **9**, **11**, **12**). Differential sensitivity is thus correlated directly, not with the prevailing central nervous excitation, but with its *complement*, *i.e.*, with the excitation potentially available for stimulation at the time the judgment is made. Thus,

$$N_e + N_a = N_t, \qquad [A]$$

[1] For an ingenious theoretical treatment of central nerve fiber activities in relation to the electrochemical state of the cerebral fluid in which these nerve cells (in normal subjects) are immersed, see Köhler (**16**).

where N_t is the total amount of excitation per unit time initially available under the physical and psychophysiological conditions of the experiment; and where N_e is the amount of excitation per unit time aroused by way of peripheral stimulation under specified conditions. N_a is accordingly the amount of excitation per unit time potentially available at the moment the discrimination in question takes place. Equation $[A]$ is purely neurophysiological in conception, and it has applications quite apart from the interpretation of data of differential sensitivity *per se* (**10**).

The constant quantity hypothesis, as we have employed it, assumes that the eventuation of a constant number of impulses in unit time in the central nervous system is the condition necessary for the occasion of a just noticeable increase in subjective intensity.

We shall presently (*vide infra*) utilize these ideas to interpret the results obtained in the present experiments, but first we must consider relevant physiological facts.

Tension receptors probably possess the property of adaptation during exposure to stimulation (**3, 4, 17**). Single end-organs are said to "exhibit a progressive decrease in the capacity for response, as the result of long-continued previous activity. . . . If after some minutes of continued stimulation the muscle is released and again stretched by the same amount, the response measured in terms of afferent impulse frequency is less than it was at first. The longer the period of previous excitation, the smaller is the second response; the longer the period of intervening recovery, the more nearly does the second response return to normal" (**3**, p. 63).

If the activities of sense-organs were the only events involved in the subjective discrimination of intensities, then we should be content to draw a correlation between the facts of differential sensitivity and the facts of sense-organ activities. However, as necessary as it is to know the relation between the stimulus and sense-organ action, the presence of neural activities tends in general to discount the usefulness of such direct correlations.

An experiment by Field and Brücke provides evidence

which supports this point. These workers found that the refractory period of nerve increases under the condition of continued electrical stimulation at constant frequency, and the time required for the refractory period to return to its normal value was found to be a direct function of the strength of the exposure (**5**; *cf.*, also **8**). Hence, nerve fibers themselves, like muscle-fibers and sense-organs, are subject to the general laws of adaptation (or 'fatigue'), as well as the principle of diminishing returns, and in general we cannot expect proportionate correspondence between (*a*) stimulus-intensity *vs* sense-organ data and (*b*) stimulus-intensity *vs* sensory discrimination data.

The particular implication of these facts for human intensity-discrimination data is that a one-to-one relation probably does not exist between the impulse-frequency for sensory end-organs and impulse-frequency for nerve. Intimately associated with this implication, moreover, is the further presumption that the relation between high impulse-frequencies per unit time in successive neurones is not linear. In view of the actual number of successive neurones involved in transmitting the effects of variations in end-organ activities due to stimulation, non-linearity must be the general rule.[2]

These inferences are general and apply to the understanding of data from any department of sense (*cf.*, *e.g.*, **15**). We shall now utilize these facts and ideas in our interpretation of the principal results obtained in the present experiments for kinesthetic differential sensitivity.

During exposure, the period of time during which the involved proprioceptive end-organs and peripheral nerve fibers are refractory may be assumed to increase by an amount which is an increasing function of the exposure itself (**1**, **4**, **5**). In other words, the greater the exposure ($= W \times t$), the smaller is the amount of neural excitation available for stimulation by way of a unit increase in the stimulus. Now if the perception of a just noticeable incre-

[2] Only in very special instances (*e.g.* extremely small values of the stimulus) is it possible sensibly to assume an approximately linear relation between variations in particular sense-organ events and data for intensity-discrimination functions.

ment in kinesthetic intensity is contingent upon the eventuation in the central nervous system of a constant increase in the number of impulses per unit time (constant quantity hypothesis), then it follows from the availability principle that ΔW should be greater immediately after the exposure than it was immediately before, and this of course is one of the facts established by the results presented in Table I and Fig. 1.

After each exposure, log ΔW was also found to decrease continuously during recovery. This fact may be attributed to the progressive increase of available excitation in the involved end-organs and peripheral nerve fibers following the removal of the exposure (**3**, **5**). Such an increase would require progressively less and less of an increase in the stimulus at the receptors in order to eventuate in the central nervous system the constant number of impulses per unit time needed to occasion (the report of) a just noticeable increase in kinesthetic intensity.

At any moment during recovery, log ΔW was found to vary directly with the exposure-times. Physiologically, not only the impulse-frequency of the proprioceptive end-organs and nerve decreases under continued stimulation, but also the amount (number of impulses per unit time) of this decrease varies directly with the exposure (**2**, **3**, **5**). Thus, the greater the exposure, the less is the amount of neural excitation available at any moment during recovery for a unit increase in the stimulus. Hence, in order to give rise in the central nervous system to the constant number of impulses per unit time necessary for the occasion of a just noticeable increase in kinesthetic intensity, log ΔW must at any given moment during recovery vary directly with the exposure-time when the intensity of the exposure is parameter.

Summary

Experiments were performed to obtain information concerning the course of kinesthetic adaptation. Immediately following exposure ($= W \times t$), kinesthetic differential sensi-

tivity ($= 1/\Delta W$) was measured under specified conditions during recovery-time ($= t$, in secs.). Exposure-time was varied (4–256 secs.); exposure-intensity (= 4000 grm.) was parameter. All measurements were made by way of the method of limits. A 200 grm. weight was used as standard.

Three major facts were established by the measurements. For each of two practised observers, differential sensitivity as a function of post-exposure time was found to increase continuously, finally approximating its nominal (pre-exposure) value. At any given moment during the recovery interval, differential sensitivity was found to vary inversely with the duration of the exposure. The time required for recovery varied directly with exposure-time.

These facts were interpreted in terms of ideas which are consistent with experimentally established neurophysiological fact.

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STUDIES IN THERMAL SENSITIVITY: 9. THE RELIABILITY OF SERIATIM COLD-MAPPING WITH UNTRAINED SUBJECTS

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A knowledge of the consistency with which thermal sensitivity can be mapped is of interest, not only for itself, but also as a basis for further research. If reasonably high reliability can be obtained with repeated mappings, it indicates: (*a*) that the sensitivity of the skin is relatively stable; (*b*) that the experiences can be consistently reported.

The importance of the problem was recognized some years ago by Dallenbach.[1] Impressed by the poor results obtained with repeated mappings in their student laboratory, he set out to discover and control all of the significant variables. A long series of preliminary tests disclosed a dozen of these which previously had been largely neglected. The final procedure which he developed stands as a model of technical excellence. The three observers were given a long course of training before the start of the main experiments, in which a stamped grid was carefully maintained on the upper arm of each observer and mapped for cold and warm at the same hour of each of the four days (Monday, Wednesday, Friday and Monday).

The maps for cold (1 mm diam. stimulator at 8–9° C.) are shown in the upper half of Fig. 1. Even casual inspection reveals a certain family resemblance among the four maps for a given area, but a statistical statement of reliability is harder to achieve. High degrees of correspondence are indicated by the 'student method' and by the 'absolute

[1] Dallenbach, K. M., The temperature spots and end-organs, *Amer. J. Psychol.*, 1927, **39**, 402–427.

method' of computation, but Dallenbach himself points out that neither method is satisfactory.[2]

A graphic representation shows better the true nature of the findings. At the bottom of Fig. 1 are large composite

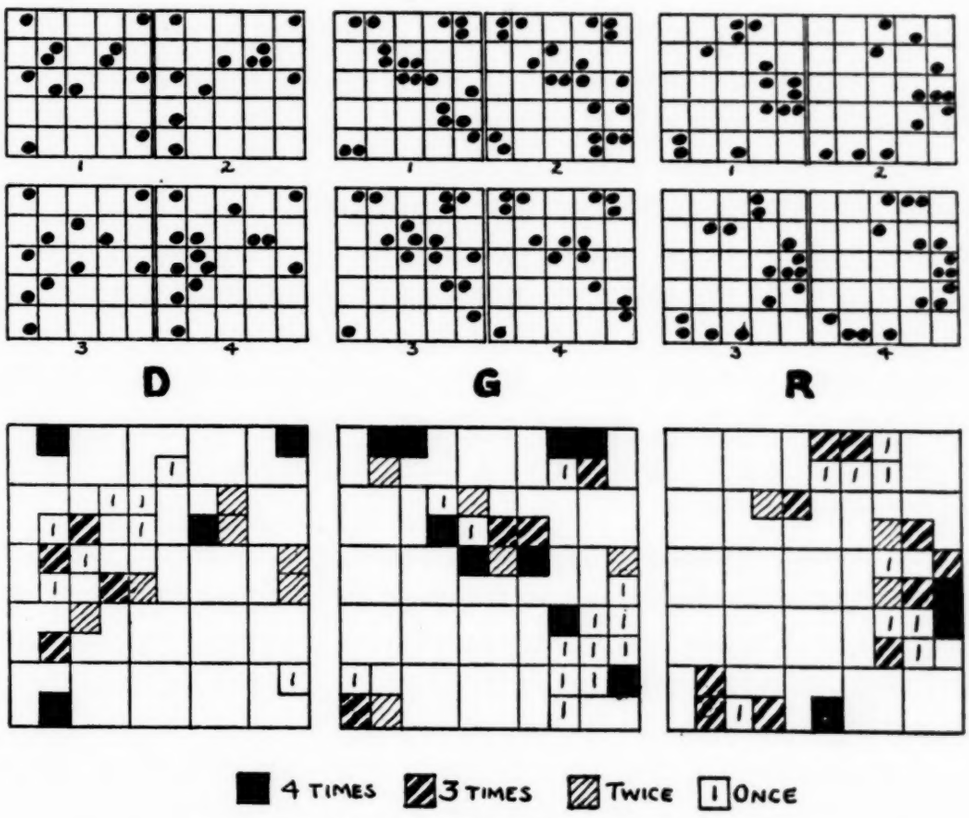

FIG. 1. Replotting of Dallenbach's cold-mapping.

maps on which are indicated the *number of times* each mm square was reported 'cold' during the four trials. Among the 22 positive squares on D's map, for example, 4 were re-

[2] Statistically, both methods are practically worthless, because high scores might be obtained by pure chance. In the 'student method,' the correspondence of one map with another is determined by the percentage of spots which are identically localized or fall within 1 mm of one another. This actually means that each square on the first map 'corresponds' to 9 squares on the second. Thus, it would be possible to scatter 15 spots on the first map so that they completely blanketed all the squares on the second. Then, no matter how random the arrangement on the second map, a 'correspondence' of 100 percent would be forced. In the 'absolute method,' the identical squares on the two maps are counted and this divided by 100 gives the correspondence. An example will show the fallacy. Imagine 5 spots down the left-hand edge of one map and 5 down the right-hand edge of the other. Obviously, the true correspondence is nil, but the 90 identical *blank* squares would give a fictitious correspondence of 90 percent.

ported cold on all four occasions, 4 three times, 6 twice and 8 only once. Or, considering the total of 48 reports of cold during the four days, 28 could be called 'consistent' (reported 3 or 4 times from the same square); whereas the remaining 20 were reported only once or twice from the same square. Similar results were obtained with observers G and R.

Such a large percentage of 1's and 2's provides no very satisfactory evidence of consistency . . . on the face of it, quite the contrary. We are faced with a dilemma. If 'cold spots' are stable entities, the mapping must be at fault. The experimenter must have misplaced his stimulator rather frequently, or the observer must have made numerous errors in reporting. If the mapping is satisfactory, the so-called 'cold spots' must be highly inconstant. Even if we allow for an occasional error on the part of the experimenter or the observer, the great majority of them appear to be here today and gone tomorrow.

Are such inconsistent 'cold spots' worth considering as entities at all? What is the point of declaring that there are (say) 12 cold spots to a square cm, if the 12 we locate today are not the same 12 we found yesterday . . . or if an average of 12 means a total of 22 in four mappings?

Let us discard for the moment the concept of so many discrete cold spots per square cm. Let us examine the composite maps simply as charts which indicate roughly the parts of the area which respond to a 1 mm stimulator at 8–9° C. The first thing we notice is that there are no *isolated* squares anywhere on the maps, except at the very edges where we cannot know what lies beyond. Then we observe that the marked squares are grouped into sizable clusters. Finally, we might speculate that the 4's and 3's in these clusters look remarkably like peaks of sensitivity, with the 2's and 1's indicating less responsive regions.

Some of the apparent anomalies of the maps now make perfectly good sense. For instance, the patch of nine 1's in the lower right-hand corner of G's map no longer needs to be considered as a concentrated case of poor work on the part of experimenter and observer. It becomes a 'valley' between

twin peaks. Likewise, the string of seven 1's in the upper right-hand part of D's map fits in perfectly well with the general conformation of that region.

Viewed in this way, all three of the maps show an orderly, if non-uniform, scheme of distribution . . . which implies consistency in the mapping. Unfortunately, there is no direct proof. We have explained away the apparent unreliability of the mapping by assuming a certain non-uniform scheme of distribution in the skin sensitivity itself. We have no final evidence to show that this hypothesis is correct.

The ambiguous outcome of Dallenbach's study points to the need for a different technique. A single mapping at each session is not sufficient. *Seriatim* stimulation during each period is required to establish independently the reliability of the mapping. Every square must be tested, not once, but a number of times at each session. Then comparison on a statistical basis will be possible.

Dallenbach's research was performed upon three highly-trained observers. What sort of results might we expect from totally-untrained subjects? Will their performance really be as poor as the usual student laboratory work indicates? Is it possible that, under fair conditions, completely untrained individuals might show good records of consistency?

These are not purely academic questions. In many instances, it is possible to secure a large number of student-subjects for a few hours apiece, but difficult to arrange for long training programs. If initially-good subjects can be found in such a group, valuable data might be obtained with only the limited training available. Or again, large numbers of individuals might be studied in a minimum of research time—for example, to outline the range of individual differences in some phase of thermal sensitivity. In any event, untrained subjects should show us the very worst we can expect from the seriatim method as a research technique. If it yields satisfactory results with them, there can be no question of its value when applied to those with ample training.

Procedure

The chief features of the procedure may be summarized as follows:

1. *Skin-marking.*—Instead of the traditional grid, a checkerboard of 50 squares was stamped on the skin with printer's ink. This was found to aid accurate placement of the stimulator, and had the additional advantage that it could be renewed if necessary. Although the whole figure might be distorted because of the elasticity of the skin, the individual squares could be restamped one by one with a minimum of displacement.

2. *Stimulator Sizes.*—Stimulators with tip diameters of 2 mm and 3 mm were used. Preliminary experiments showed that the smaller sizes rarely gave a sufficient range of discriminable experiences. The 1 mm size used in the Dallenbach study, for instance, results in a very large percentage of 0's in most subjects, which is undesirable in a study of reliability. If we discard provisionally the concept of 1 mm 'cold spots' as sacred entities, there is no particular point in using the 1 mm size.

3. *Seriatim Method.*—During each one-hour period, every square in the checkerboard pattern was stimulated 6 times, at intervals of 7–10 minutes. An ordinary brass hand-stimulator was used, with no particular device to insure uniform pressure. The temperature (17° C.) was maintained within 1° C. by rapidly circulating water.

4. *Reports.*—Subjects were instructed to report in three categories: 2 for strong cold, 1 for weak cold and 0 for neutral. This scheme was used in place of simply 'cold' and 'neutral' to provide a broader base for scoring. Subsequent events indicated that a still larger number of categories might have been used.

5. *Order of Stimulation.*—To avoid any possibility that the subject might memorize a sequence of reports, an approximately random order of stimulation was employed. The black squares and the white squares of the checkerboard pattern were stimulated separately, in rows of five at a time. The sequence of these rows was changed with each trial, and sometimes the stimulation proceeded from right to left in a row, sometimes the reverse.

6. *Individual and Group Experiments.*—In the individual experiments, the author acted as experimenter and two students alternated as subject and recorder, for two consecutive one-hour periods, making 12 rounds in all. In the group experiments, a student acted as experimenter for each group, while two others alternated as subject and recorder. The group schedule was:

1A and 1B—Consecutive periods Monday afternoon.
2—One hour Tuesday morning.
3—One hour Wednesday morning.
4A and 4B—Consecutive periods Thursday morning.

Only two of the 15 subjects (4 women, 11 men students) were able to complete all six periods, but the majority came for four periods during which the same checkerboard pattern was maintained (renewed if necessary) and stimulated six times at each period. In both the individual and the group experiments, the marked area was on the volar surface of the left forearm.

7. *Statistical Treatment.*—The three categories 2, 1 and 0 are ordinal, not cardinal numbers. However, the best statistical assumption seems to be that '1' lies half-way between '0' and '2.' Then a quantitative score for each square can be obtained simply

by adding the numbers reported from that square during a period. The correlation between any two periods can be computed by the product moment formula.[3]

Variables and Artifacts

The reliability coefficients thus obtained will necessarily be *resultants* of a number of possible variables which seem to be inherent in the situation. These include: (*a*) changes in the sensitivity of the area as a whole; (*b*) changes in the responsiveness of individual squares; (*c*) general ability of the subject to maintain standards of judgment during a period; (*d*) shifts in the level of criteria from period to period; (*e*) improvement of discrimination with practice. Unfortunately, it is not possible to isolate the individual influences of these variables by any gross consideration of results. For example, a change in the sensitivity of the area as a whole has exactly the same effect on the scores as a shift in the general level of the subject's criteria. Again, changes in the sensitivity of individual squares produce irregularities which are duplicated by the subject who cannot maintain consistent standards of judgment.

In some cases, the detailed evidence is quite suggestive. For instance, a square might show 6 reports of '2' at one period and 6 reports of '1' at another, with no parallel change in the general level of scores. Clearly, each score alone is perfectly consistent; so the chances are that the sensitivity of the square itself has changed. On the other hand, when a number of squares show mixtures of 2's, 1's and 0's, it is probable that we are dealing with a poor subject. Sharpening of discrimination with practice is indicated by an increasing tendency of the scores to group closely around 0, 6 and 12. At the start, many intermediate scores result because a square is sometimes called '2' and sometimes '1'; or sometimes '1' and sometimes '0.' As the subject develops more skill and the boundaries between categories become more precise, these borderline cases tend to fall consistently into one category or the other. Although this is a highly desirable development, it results in a reduction in the computed reliability coefficient when early results are compared with those late in the series.

In addition to these variables which seem to be inherent in the situation, there are a number of possible *artifacts* which can be wholly or partially controlled. Some of these would tend to increase, some to decrease the computed coefficients.

Artifacts which would tend to *increase* the coefficients include:

1. Adoption of a fixed sequence of reports by the subject, regardless of the actual results of stimulation. This was entirely eliminated, it is hoped, by the random order of stimulation.

2. Cues from the experimenter. This probably played no part, since the experimenter himself usually did not know what the previous reports from the square had been.

3. Collusion between subject and recorder. Since subject and recorder were usually in keen competition, this is highly improbable in the present instance.

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[3] Although a surprisingly large number of cases of 'six of a kind' occurred, these are not necessary in order to establish consistency. For example, a square with reports of 2-1-1-2-1-2 in one period and 2-2-1-1-2-1 in the second is perfectly consistent. The only questionable cases are those in which the same score is arrived at by a different combination of numbers. This is possible only when the extreme reports (2 and 0) occur in the same square during the same period. In the better subjects, this was relatively rare. Typically, for the intermediate scores, 2's were mixed with 1's and 1's mixed with 0's.

4. Artificial elimination of one category by the subject. Perhaps the best answer to this is that practically all of the highest coefficients were obtained by subjects who clearly used the full range of categories.

Among the artifacts which would tend to *decrease* the obtained coefficients are:

1. The effects of repeated stimulation upon sensitivity—especially the negative effect of adaptation. It may seem strange that 2-second stimulations 7–10 minutes apart could have any such influence, but this seems clearly indicated in some cases.

2. Mis-location of the squares in restamping. This would enter only in that minority of cases where the markings faded to such an extent that they had to be renewed.

3. Errors of the experimenter, including misplacement of the stimulator, uneven pressure and failure to get the stimulator tip flat against the skin. Especially with untrained experimenters, such artifacts must have entered to some extent.

4. Errors of the recorder, such as writing down an incorrect number of making the entry in the wrong place on the data sheet. This probably occurred occasionally.

In summary, it seems probable that the sum total of the artifacts would tend to *decrease* rather than to increase the computed coefficients. It is safe to say, therefore, that the reliability coefficients given in the ensuing tables are too low, if anything, rather than too high.

Results

The results of the *individual* experiments are summarized in Table 1. With both 2 mm and 3 mm stimulators, the correlations between successive periods are .85 or better in two-thirds of the cases and above .75 in the remainder. These represent a combined measurement of the stability of sensitivity and the consistency of the subjects in reporting, somewhat reduced by the artifacts previously mentioned. On the whole, then, the performance of these totally untrained subjects seems highly satisfactory. Indeed, reliability coefficients of .93 and .96 could scarcely be exceeded by the most highly-trained observer.

The coefficients for the *group* experiments are shown in Table 2, where all possible intercorrelations are given. Since the experimenters in this work were as untrained as the subjects, a somewhat lower general level of performance is to be expected. But the peak performances compare quite favorably with those obtained on the individual basis. Six subjects reached .85 or better and six more .75 or better. The remaining three were decidedly inferior, two of them barely getting above .65 and the other giving little better than a random performance. Naturally, the correlations

TABLE 1

INDIVIDUAL EXPERIMENTS

3 mm Diam. Stimulator—17° C.

Subj. Init.	Correl. × 100	Distribution of Scores				
		0–1	2–3–4	5–6–7	8–9–10	11–12
FLB	93	31	7	4	8	0
		29	7	13	1	0
SBP	91	14	12	18	5	1
		16	13	18	3	0
JLB	87	3	11	9	11	16
		1	7	14	14	14
HFJ	85	2	9	9	9	21
		2	5	17	5	21
MBR	81	0	7	16	10	17
		0	2	6	19	23
FBS	77	5	6	9	8	22
		1	2	3	6	38
2 mm Diam. Stimulator—17° C.						
HLR	96	24	8	12	5	1
		27	7	12	4	0
HWT (1)	86	5	10	9	11	15
		1	8	20	10	11
HWT (2)	89	3	6	13	14	14
		2	2	19	10	17
RMS	85	6	12	24	7	1
		5	8	16	13	8
HTSH	80	21	12	10	7	0
		25	13	9	3	0
JGH	79	11	18	15	6	0
		14	14	21	1	0

fall off somewhat with two and three days intervals, but are still at a respectable level.

The distribution of scores for the group experiments (Table 3) indicates considerable shifting from period to period. As previously noted, it is difficult to determine the cause in most instances. With subject TR, however, there is a continual downward trend, which might be taken as indication of a

change in sensitivity of the area as a whole. It should be noted that this subject showed fairly high correlations when only successive periods were compared, in spite of marked negative adaptation effects during the course of every period. Improvement of discrimination with practice is clearly shown by subjects KK, AED and JH, as evidenced by the increasing grouping around the category levels. Note that in KK's final period the intermediate scores 2–3–4 and 8–9–10 disappeared entirely.

TABLE 2

CORRELATIONS × 100—GROUP EXPERIMENTS

3 mm Diam. Stimulator—17° C.

Interval	One Hour		One Day					Two Days				Three Days			
Periods	1A	4A	1A	1B	2	3	3	1A	1B	2	2	1A	1A	1B	1B
Subj. Init.	1B	4B	2	2	3	4A	4B	3	3	4A	4B	4A	4B	4A	4B
KK....	87	84	88	92	89	89	89	83	89	77	81	76	75	77	73
AED...	74	94	70	84	85	90	87	70	78	86	90	63	67	80	82
WB....	79		87	81	89	80		80	85	85		85		79	
AMC...	96		91	92	91			82	92						
DE....	77		78	74	80			73	66						
MLF...	78		77	70	77			78	72						
JH.....	76		72	89	85			77	84						
ADP...	75	82	64	72						91	62				
TR.....	78		82	81	63			62	52						
RBS....	48		19	∞	39			51	20						
CD....					54	66				57					
FSF....					75	72				57					
WK....					70	62				66					
REB...					84										
JED...		93													

Possibly more important than the individual correlations is the general consistency over several days' time as shown in Fig. 2, where average scores (rows) are plotted against individual scores (columns). An example may make this somewhat unorthodox graph clearer. With subject KK, there were 8 squares with an average score of '6' for the entire session. For each of these squares, we have available 6 individual scores, or 48 in all. Examination of the chart shows that 42 of these 48 scores were identical with the average score or within one point of it. Among all of the

better subjects, the clustering of values along the diagonal is notable. The mean deviation for any average score is typically less than one step interval and 'wild shots' are comparatively

TABLE 3

DISTRIBUTION OF SCORES—GROUP EXPERIMENTS

3 mm Diam. Stimulator—17° C.

Subj. Init.	Period	0–1	2–3–4	5–6–7	8–9–10	11–12
KK.....	1A	2	8	13	14	13
	1B	3	10	15	11	11
	2	0	9	15	12	14
	3	1	4	24	5	16
	4A	1	3	26	9	11
	4B	2	0	28	0	20
AED.....	1A	0	2	14	20	14
	1B	0	2	15	17	16
	2	0	2	20	8	20
	3	0	0	16	11	23
	4A	0	0	17	9	24
	4B	0	0	19	3	28
WB.....	1A	3	12	12	12	11
	1B	2	13	7	16	12
	2	4	11	10	11	14
	3	5	7	11	15	12
	4A	2	7	12	17	12
AMC.....	1A	9	4	9	12	16
	1B	9	4	9	10	18
	2	8	5	9	7	21
	3	10	2	4	12	22
DE.....	1A	3	5	13	12	17
	1B	0	7	9	14	20
	2	5	6	4	11	24
	3	1	5	8	10	26
MLF.....	1A	6	9	10	13	12
	1B	2	6	12	18	12
	2	3	10	4	18	15
	3	3	13	10	15	9
JH.....	1A	3	8	11	18	10
	1B	2	10	12	14	12
	2	5	6	19	6	14
	3	4	6	21	4	15
ADP (1).....	1A	0	6	8	13	23
	1B	0	3	6	16	25
	2	0	0	5	14	31
ADP (2).....	3	3	4	10	17	16
	5A	1	7	11	17	14
	5B	2	6	7	17	18

TABLE 3 (*continued*)

Subj. Init.	Period	0–1	2–3–4	5–6–7	8–9–10	11–12
TR	1A	3	9	24	10	4
	1B	7	11	23	7	2
	2	12	17	17	4	0
	3	16	17	15	1	1
RBS	1A	0	1	4	27	18
	1B	0	0	2	16	32
	2	0	0	6	18	26
	3	0	1	7	13	29
CD	2	0	17	30	2	1
	3	0	9	36	5	0
	4A	0	1	29	18	2
FSF	2	0	6	19	18	7
	3	0	8	23	13	6
	4A	0	2	27	18	3
WK	2	1	11	14	16	8
	3	3	8	23	14	2
	4A	0	6	23	16	5
REB	2	6	19	12	11	2
	3	9	11	21	5	4
JED	5A	4	4	11	13	18
	5B	3	6	18	9	14

rare. This makes the average score for a square a highly meaningful value.

The significance of these average scores is likewise indicated by the maps in Fig. 3. The number in each square of the map is the average score from all available data. It must be remembered that these squares were not stimulated in a fixed order. All of the black squares were stimulated first; then all of the white squares, each group in a random fashion. Yet, when the two sets of data are put together, a striking *orderliness* is revealed. Squares of high sensitivity are not scattered irregularly through the map, but typically occur in fairly large clusters. Frequently, the tapering-off to lower and lower levels can be traced. Even those numbers which occur very infrequently tend to be grouped. Notice, for instance, the vertical string of 6's in the map for AED or the block of 3's, 4's and 5's in that of KK. Possibly the most significant feature of these maps is the indication of lawfulness

even when the reliability coefficients are fairly low. The average scores from a sufficient number of trials may be meaningful in such cases, although it is impossible to establish high consistency when period is compared with period.

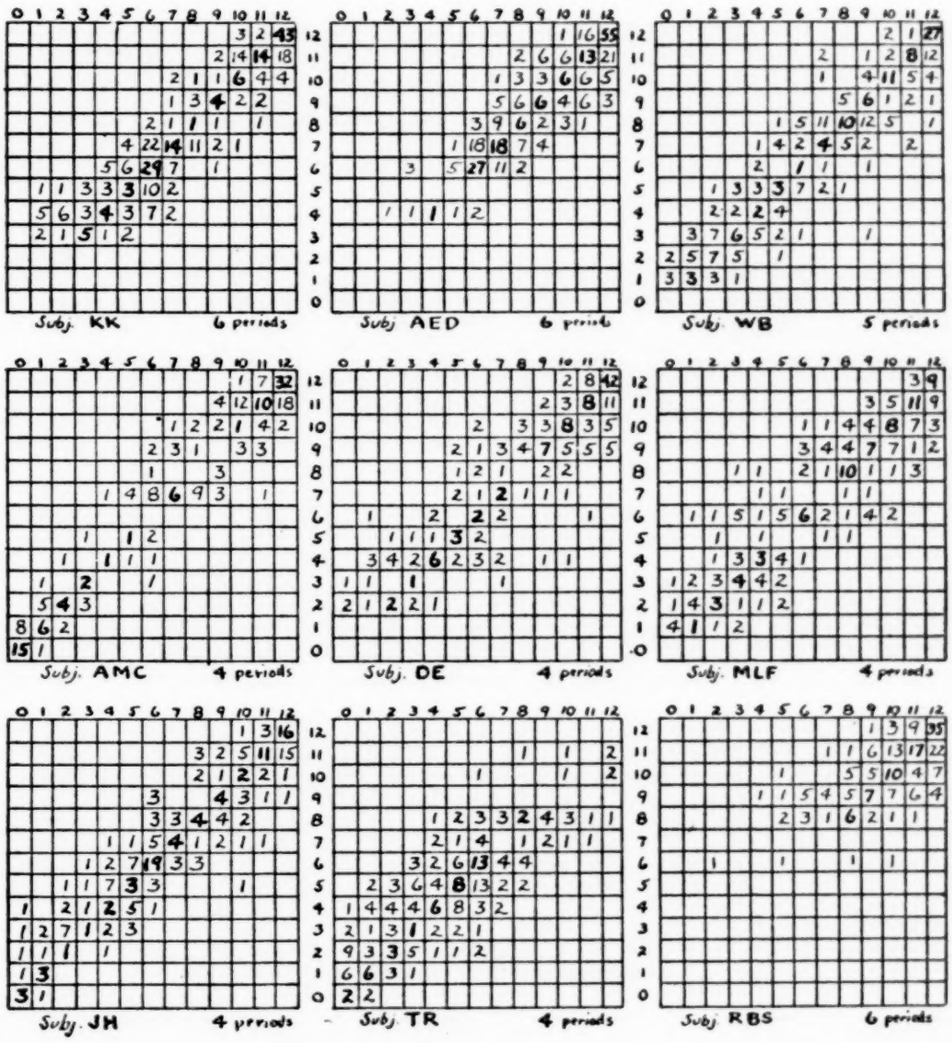
Subj. KK 6 periods
Subj. AED 6 periods
Subj. WB 5 periods
Subj. AMC 4 periods
Subj. DE 4 periods
Subj. MLF 4 periods
Subj. JH 4 periods
Subj. TR 4 periods
Subj. RBS 6 periods

FIG. 2. Average against individual scores.

As a matter of interest, maps derived from the individual experiments with 2 mm diam. stimulator (average of only two periods) are shown in Fig. 4. While the orderliness of these maps is much less striking than in Fig. 3, this may in part be an artifact of the smaller number of cases used in computing the average scores.

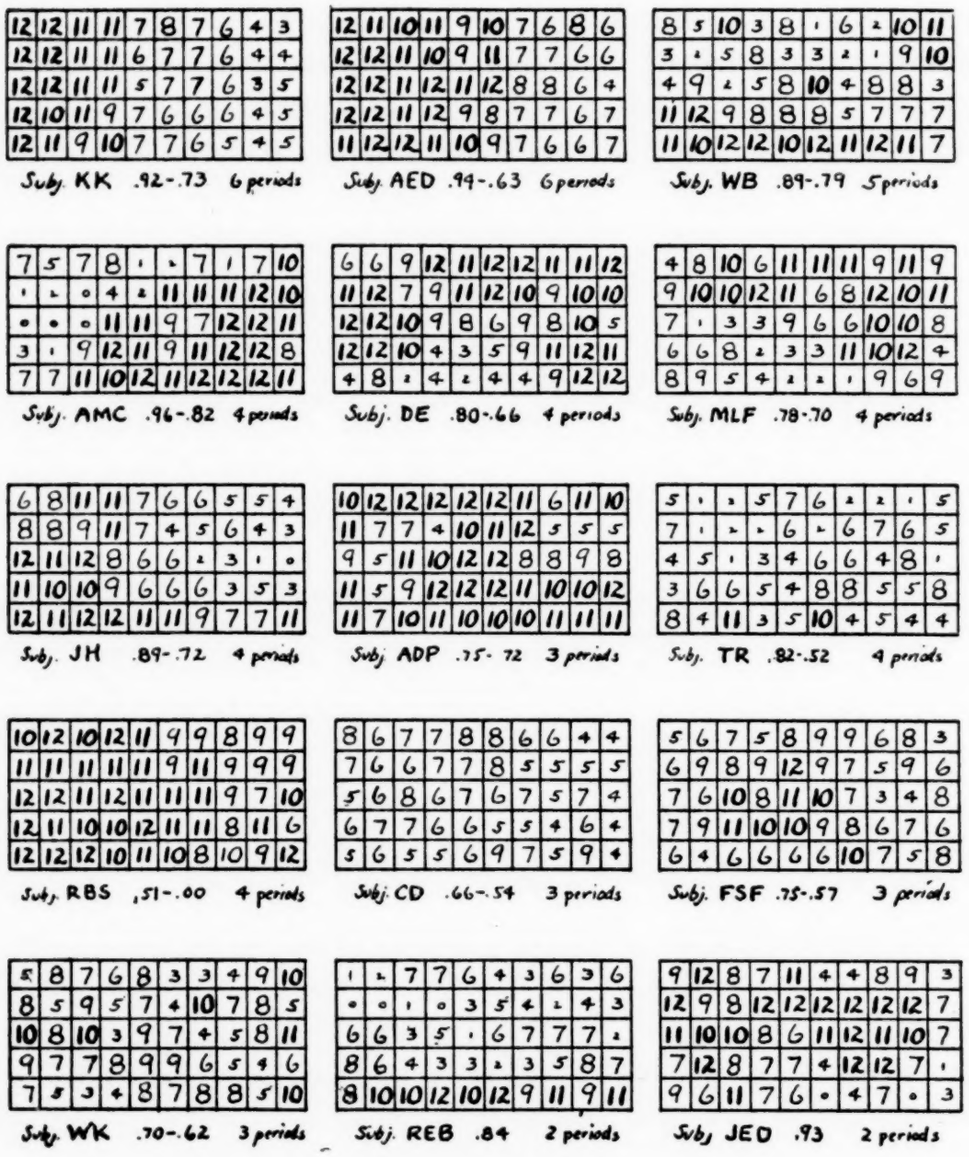
Subj. KK .92-.73 6 periods
Subj. AED .94-.63 6 periods
Subj. WB .89-.79 5 periods
Subj. AMC .96-.82 4 periods
Subj. DE .80-.66 4 periods
Subj. MLF .78-.70 4 periods
Subj. JH .89-.72 4 periods
Subj ADP .75-.72 3 periods
Subj. TR .82-.52 4 periods
Subj. RBS .51-.00 4 periods
Subj. CD .66-.54 3 periods
Subj. FSF .75-.57 3 periods
Subj. WK .70-.62 3 periods
Subj. REB .84 2 periods
Subj JED .93 2 periods

FIG. 3. Maps of average scores—3 mm stimulator.

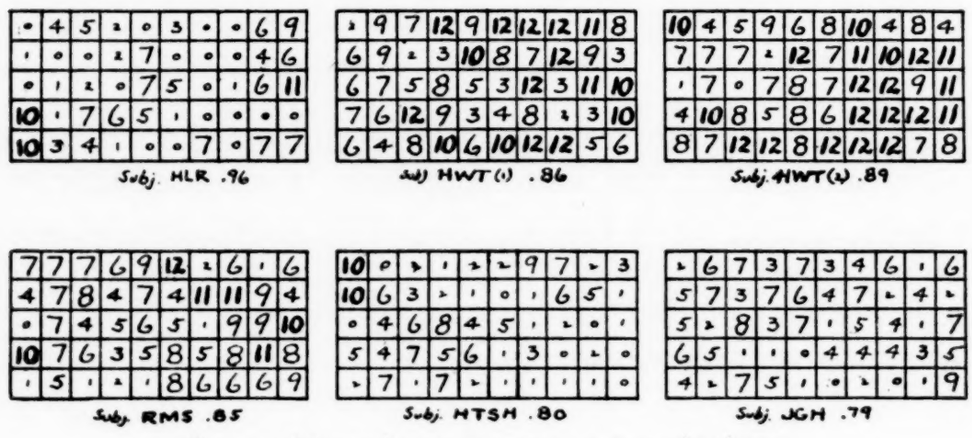

FIG. 4. Maps of average scores—2 mm stimulator.

Significance of Results

From the foregoing data, it becomes evident that seriatim mapping provides a promising research technique for the *quantitative* study of the effects of low temperature stimulation. Four essential steps suggest themselves:

1. Preliminary tests to determine reliability coefficients. There is some indication that good subjects improve rather rapidly; whereas initially-poor subjects show little benefit from training.

2. Sufficient training to establish reasonably consistent standards of judgment.

3. Establishment of a proper scheme of categories. Too many numbers are confusing to the untrained subject. Too few of them result in an artificial grouping of scores around the category levels as discrimination improves.

4. Sufficient number of tests for the reliable determination of average scores. Statistically, the reliability increases with the square root of the number of cases. Practically, a number of other factors must be taken into consideration.

Some of the *problems* which might profitably be investigated with such a technique include:

1. The effect of stimulator size. A rough comparison of the 1 mm maps from the Dallenbach study with the 2 mm and 3 mm maps from the present investigation shows interesting possibilities.

2. The effect of stimulator form. It has already been shown that the shape of stimulator, as such, markedly affects adaptation time [4] and may also alter the original intensity of experience.

3. The effect of stimulating temperature, especially at levels close to the limen.

4. Shifts in sensitivity over an extended period of time. There is some indication that extremely strong and extremely weak squares tend to remain stable, while those in the intermediate levels do most of the shifting.

[4] Jenkins, W. L., Studies in thermal sensitivity: 2. Adaptation with a series of small rectangular stimulators, *J. Exper. Psychol.*, 1938, 22, 84–89; 3. Adaptation with a series of small annular stimulators, *J. Exper. Psychol.*, 1938, 22, 164–177.

The outcome of a systematic program of this kind should be a clearer understanding of the *necessary* scheme of cold-receptor distribution. The usefulness of the concept of discrete 'cold spots' (as marked by a very small stimulator) is already under suspicion. It should be possible to demonstrate conclusively whether the actual distribution of cold sensitivity can be explained in terms of such 'cold spots' at all. The present results suggest as a more fruitful hypothesis the assumption of a large number of minute receptors, with great differences in the density of their distribution. Thus, peaks of sensitivity would appear where the density is the greatest and valleys where it is least . . . the so-called 'cold spots' being merely artifacts of the method of stimulation employed, particularly stimulator size and temperature. Such an assumption would also change materially the course of our search for the receptors involved.

Any such speculation, however, should wait upon the results of much further research—for which the seriatim technique seems admirably adapted.

Summary

When the results of Dallenbach's study with trained observers (four single cold-mappings on different days with a 1 mm diam. stimulator at 8–9° C.) are replotted in terms of composite maps showing the number of times each mm square was positively reported, no high consistency is established. Either the mapping must be faulty, or the 'cold spots' are inconstant. If the concept of discrete 'cold spots' is discarded, the composite maps may be viewed as an orderly scheme of peaks and valleys of sensitivity, from which consistency in mapping may be inferred, but is not proved. This ambiguous outcome points to the need for a seriatim technique for the independent determination of reliability.

In the present study, seriatim cold-mapping was carried out upon totally untrained subjects with 2 mm and 3 mm stimulators at 17° C. Each square of a checkerboard pattern was stimulated 6 times during a period; repeated mappings

being made the same day and also for several days in succession. Three indications of consistency are found: (1) reliability coefficients of .85 or better are obtained in the majority of cases when successive periods are compared; (2) charts of average against individual scores show low mean deviations and few 'wild shots'; (3) maps derived from average scores indicate a high degree of orderliness, even when the reliability coefficients are low. It is concluded that seriatim cold-mapping is a promising research technique. Certain avenues for further investigation are suggested.

(Manuscript received August 30, 1938)

THE WEAKENING OF ONE THORNDIKIAN RESPONSE FOLLOWING THE EXTINCTION OF ANOTHER [1]

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In discussing the varied effects resulting from the extinction of a conditioned response Pavlov says,

"Experimental extinction of any single conditioned reflex results, not only in a weakening of that particular reflex which is directly subjected to the extinction (*primary extinction*), but also in a weakening of other conditioned reflexes which were not directly subjected to extinction (*secondary extinction*)." (Parentheses Pavlov's.) (10, p. 54.)

Although the validity of this effect has been questioned (8), other experimenters (1, 2) have confirmed Pavlov's findings.

While secondary extinction is now a recognized phenomenon in conditioning, Thorndike (15, p. 110) has stated that this is one of the "features of the connection established in a conditioned reflex which do not now seem to have any counterparts in ordinary learning." However, he added that "more extensive observations and deeper insights may reveal parallelisms." Such parallelisms between conditioning and Thorndikian [2] rewarded learning have been suggested by a number of writers. Hull (4, 6) deduced many of the phenomena of trial and error learning from Pavlovian principles, postulating that the individual Thorndikian responses exhibit characteristics similar to those of the conditioned response.

[1] The writer wishes to express his thanks to Professor Clark L. Hull, in whose laboratory this investigation was performed, for valuable suggestions and criticism during the performance of the experiment and preparation of the manuscript.

This is the third of a series of studies presented as a dissertation to the faculty of the Graduate School of Yale University in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Psychology.

[2] The 'rewarded' response has been called a Type II conditioned reflex by Konorski and Miller (7) and a Type I CR by Skinner (13). To avoid confusion and because of Thorndike's priority in this field, it will be called 'Thorndikian' here, following Hull's (6) usage.

While several other writers (**3**, **9**, **13**) share this point of view in whole or in part, the experimental comparison of these two types of learning is far from complete.[3]

Skinner (**12**) has shown that the extinction curve for the rewarded type of response has the wave-form characteristic of the extinction of conditioned reactions. In previous articles (**16**, **17**) the writer reported that with certain minor differences the Thorndikian response exhibits acquisition, extinction, spontaneous recovery, and retention of a kind also found in conditioning. It is the purpose of the present experiment to test for the secondary-extinction effect with two Thorndikian responses. This was accomplished by measuring the effect of extinction of one response upon the resistance to extinction of the other.

Apparatus and Procedure

The two sound-shielded boxes used in this experiment have been more fully described in an earlier article (**16**) and were essentially similar to those designed by Skinner (**11**), with the exception that the rats could be observed through a double-paned observation-window.

In the experimental box was a short horizontal bar (H-bar) which the rat could depress to obtain food. In order that there might be an alternative response for the rat to learn, a vertical bar, 2½″ long, was attached to the shaft supporting the horizontal bar. This projected downward, and at rest was approximately one inch to the left of the center of the food tray. (See Fig. 1.) A separate marker on the polygraph recorded the movement of the vertical bar (V-bar).

Nineteen male rats of the Experimental Colony strain from the Wistar Institute were used as subjects. At the beginning of training each was approximately 95 days old and had not been used in any previous experiment. Feeding began one-half hour after the experimental work, so that during the next day's trials the animals were motivated by a 22½-hour food deprivation. The animals were separated into four groups and as closely as possible, the litter-mates were divided equally among them.

The procedure may be outlined as follows:

Days 1–4.—During this orientation period each rat was placed in an experimental box with no bar present once each day. The rat remained in the box an hour the first day and for one-half hour on each of the three succeeding days.

Days 5–6.—A rat was placed in the experimental box and was taught to operate the horizontal bar, as previously described (**16**). (Half of the rats were trained first

[3] The two types of learning may be differentiated in terms of the reaction that is acquired. In conditioning, the indifferent stimulus gains the power to evoke the response to the unconditioned stimulus. In rewarded learning a different connection is formed. Any response to the indifferent stimulus is strengthened when it is immediately followed by reward. Hilgard (**3**) has compared these types of learning more fully.

on the H-bar, the other half first on the V-bar. Extinctions were also presented in a balanced order. The procedure for the group beginning with the H-bar will be described.) The rat was allowed to obtain 20 food-pellets and was then returned to its living-quarters.

Day 7.—With the horizontal bar again present the rat was allowed to depress the bar twenty times and get twenty pellets. Altogether the rat had then received forty reinforcements on the H-bar.

Day 8.—On this morning the rat was trained to push the vertical bar sideways to obtain a pellet of food. This was done in a way similar to that used with the horizontal bar. This response was acquired comparatively easily, when learned *after* the training on the H-bar. However, the group that learned the V-bar response first took much longer to learn, as shown in Table I.

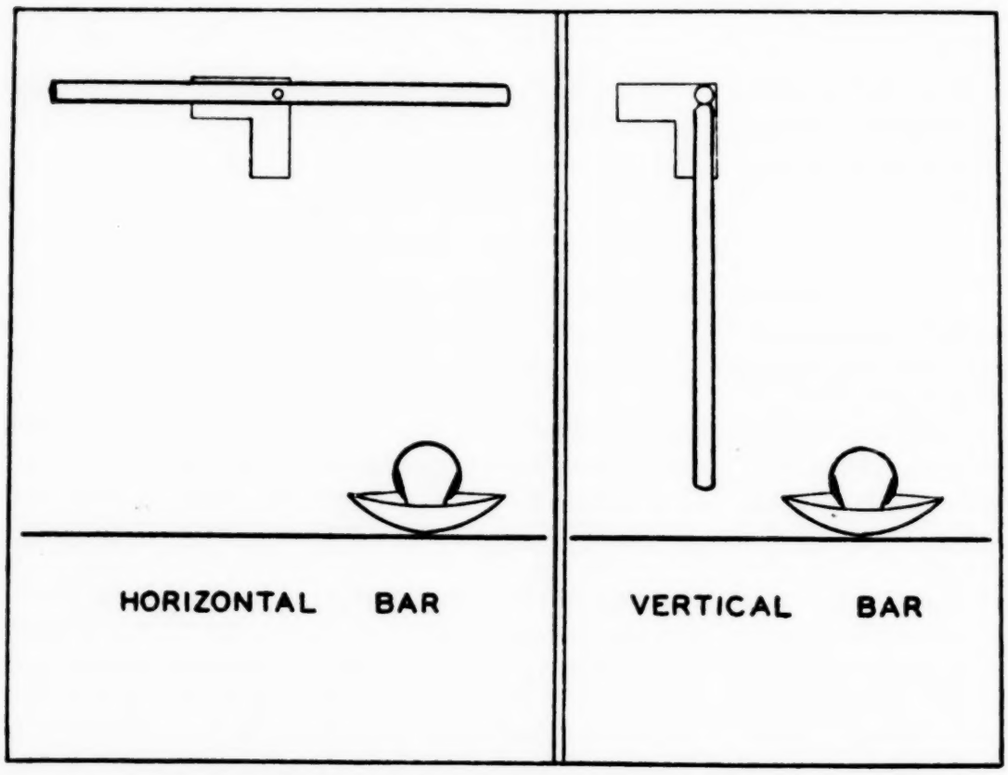

FIG. 1. Horizontal and vertical bars. At the left is the horizontal bar in position. At the right, the horizontal bar has been removed and the vertical bar attached. The H-bar can move only downward, the V-bar only to the left. The food-tray is shown at the lower right of each figure. The hole in the panel above the food-tray is for the tube delivering the pellet.

TABLE I

MEAN TIME IN MINUTES AND DECIMALS FOR FORTY REINFORCEMENTS ON SUCCESSIVELY LEARNED BAR-RESPONSES

	Bar Learned First	Bar Learned Second
Groups No.	Vertical	Horizontal
1 and 2	24.68	10.99
	Horizontal	Vertical
3 and 4	14.84	12.72

Day 9.—With only the V-bar present the rat was allowed to obtain twenty pellets, bringing the total reinforcements on the V-bar to forty.

Day 10.—The rat was placed in the experimental box with only one bar present (*e.g.* the horizontal). A switch was thrown so that depressions of the bar were not reinforced with food, and experimental extinction occurred. This was considered complete when twenty minutes had passed during which there was no response to the bar. The rat was then removed from the experimental box and placed in a small retaining cage for five minutes while the experimenter removed the first bar and put in the other (*e.g.* the vertical). The tendency to respond to this bar was also subjected to experimental extinction to the same criterion. Thus both extinctions served as measures of the strengths of the response-tendencies.

All responses to either bar, whether reinforced or not, were recorded on the polygraph. At no time during the experiment were both bars present in an experimental box at the same time.

Acquisition of Responses

With all groups the last twenty reinforcements on each bar were obtained in less time than was required for the first twenty (Figs. 2 and 3). This decrease in reinforcement-time

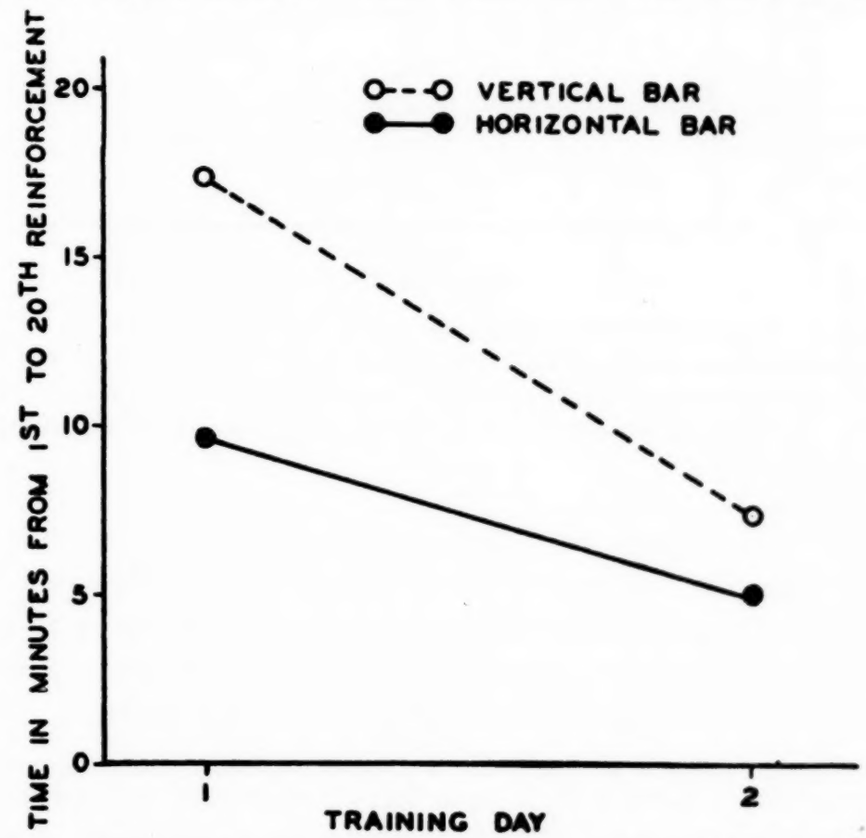

Fig. 2. Comparative acquisition-times on the two bars during the first forty learning trials. Ten rats learned the horizontal bar first and were given twenty reinforced trials each day for two days. Each point on the H-bar curve represents the mean time for the ten animals in making twenty rewarded operations of the bar. The other nine rats learned the response to the vertical bar first.

as training progressed is in agreement with earlier findings (16, 17).

From the values in Table I it can be seen that after training on either bar, the learning on the other bar proceeds more quickly than if there had been no previous training. The data also indicate that the V-bar benefits much more than the H-bar when preceded by training on the alternate reaction. This difference seems to be the result of the relatively greater difficulty with which the rats learn to

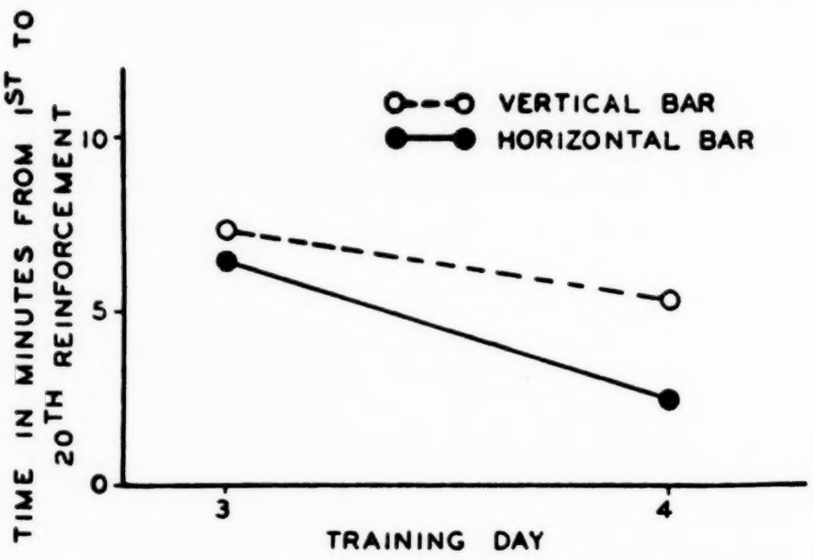

FIG. 3. Comparative acquisition-times on the two bars when all rats have previously received forty training trials on the alternate bar. After training on the H-bar, the ten rats then received twenty reinforced trials a day for two days on the V-bar. The time required is shown above. The other nine rats now received similar training on the H-bar.

operate the vertical bar,[4] but is probably not as large as the figures indicate. The greater difficulty may be inferred from the longer time spent in the initial stages of learning to push the V-bar sideways. Since with such a slow start a much larger increase in speed is possible before the limiting rate is

[4] While the horizontal bar needs only a downward pressure with either paw, the vertical bar must be pushed to the left for at least ¼". This the rat does best by standing beside the bar and pulling it with the left paw. However, this method was usually arrived at only after the rat had first learned to push the bar to the left with its nose. The change from using nose to using left paw appears in many ways to be a shift from a less to a more dominant member of a habit-family, when the less dominant member happened to be learned first (5).

reached, the difference is probably partly an artifact of the training-method.

However, one might possibly infer from the values in Table III that the vertical bar is learned less well than the horizontal with equal amounts of training. At the first extinction the values for the horizontal bar were greater than those for the vertical, no matter what the order of previous training. The means for the second extinctions seem to show the same thing. However, the strength of the tendency extinguished second is most certainly affected by the number of responses during the just previous extinction, so that this difference is the result of several factors.

Secondary Extinction

The data are presented in Table II and, with the addition of the training and extinction orders, are summarized in

TABLE II

Responses during Extinction for All Rats on Each Bar

Rat No.	First Bar	Second Bar	Rat No.	First Bar	Second Bar
	Horizontal	Vertical		Vertical	Horizontal
1	104	0	10	59	27
2	21	10	11	31	37
3	69	9	12	37	26
4	81	5	13	11	12
			14	47	29
	Mn. 69	6		Mn. 37	26
	Horizontal	Vertical		Vertical	Horizontal
5	80	21	15	42	16
6	35	3	16	19	22
7	38	3	17	35	25
8	28	5	18	26	14
9	28	31	19	22	18
	Mn. 42	13		Mn. 29	19

Table III. When the mean for the first extinction, 43, is compared with that for the second, 16, a reliable difference is found. The critical ratio based on the SE is 4.23. *During the second extinction there were, on the average,* **27** *fewer responses than during the first, indicating a reduction through secondary*

extinction of **63** *percent.* This reduction may have been affected by disinhibition when the rats were removed from the experimental box between the first and second extinctions while the bars were being changed. However, any disinhibition would presumably have decreased the secondary extinction on the second bar, and the effect occurred in spite of this.

From the structure of the experiment it seems likely that this reduction is the result of the immediately preceding extinction on the alternate bar. If this is true, then the parallelisms between conditioning and the Thorndikian type of learning become more evident. Previous experiments (**16**, **17**) have shown that the rewarded type of reaction exhibits acquisition, extinction, spontaneous recovery, and retention of a sort similar to those found in conditioning. Pending confirmation, it is now possible to add 'secondary extinction' to this list. These findings increase the probable validity of such studies as those of Hull (**6**) and Spence (**14**) in which the writers postulated that the rewarded response acts according to principles characteristically found in the conditioned response.

TABLE III

MEAN NUMBERS OF RESPONSES DURING THE FIRST AND SECOND EXTINCTION-SERIES, SHOWING THE EFFECT OF SECONDARY EXTINCTION

No. of Rats in Group	Order of Training		Mean Responses During First Extinction	Five-minute interval	Mean Responses During Second Extinction
	1st Bar	2nd Bar			
4	V	H	(1) H-bar 69		(5) V-bar 6
5	H	V	(2) H-bar 42		(6) V-bar 13
5	H	V	(3) V-bar 37		(7) H-bar 26
5	V	H	(4) V-bar 29		(8) H-bar 19

Mean for rats in all four groups	43		16
σ_M	5.69		2.50
$\sigma_{Dif.}$		6.22	
Dif.		4.23	
$\frac{Dif.}{\sigma_{Dif.}}$			

FACTORS INFLUENCING SUB-MEANS

Table III also shows the comparative numbers of responses under the various conditions. It will be noted that there

is quite a wide range of values in both the 'First Extinction' and 'Second Extinction' columns, reflecting the diverse conditions of the various groups. While an N of 19 is probably sufficient to demonstrate the secondary-extinction effect, it is doubtful whether much importance can be attached to the means for the separate groups, none of which contains more than five animals. However, pending experimental determination of the existence and size of the significant variables in this situation, a few relationships will be suggested. (The means discussed in the following paragraphs are those numbered in Table III.)

The size of mean (1) seems to be the result of several factors: (*a*) the number of reinforcements on the H-bar; (*b*) the higher resistance to extinction of this bar, which corresponds to the greater ease of acquisition during the training sessions; and (*c*) the fact that the H-bar was learned after the V-bar and probably was strengthened by 'positive generalization,' or transfer, from this previous training.

Mean (2) is also the product of three variables, the first two of which are the same as in the preceding paragraph: (*a*) number of reinforcements; (*b*) greater resistance to extinction of H-bar; and (*c*) the amount of 'interference' with the H-bar response from the interpolated training on the more difficult V-bar. It is possible, of course, that with this type of response interpolated training would have a facilitating effect. An experimental test of this would involve only a control-group with no interpolated training on the V-bar. By analogy, from results in verbal learning one would expect the V-bar learning to act as a 'retroactive inhibitor.'

Means (3) and (4) are the result of variables similar to those affecting means (1) and (2) except that here the greater difficulty in learning and operation of the V-bar would presumably reduce the number of extinction-responses. And the positive generalization from the H-bar (easier action) to the V-bar (more difficult action) is very probably different from the generalization from V-bar to H-bar.

With mean (5) the influence of secondary extinction makes the process more complex. This mean is probably the result of: (*a*) number of original reinforcements; (*b*) the

lesser resistance to extinction of the more difficult response; (*c*) the 'interference' from interpolated training on an easier reaction; and (*d*) the effect of the preceding extinction on the other bar. The secondary-extinction effect from the extinction at (1) may be roughly gauged by comparing mean (4) with mean (5). The training-order for these two groups was the same. The only difference is the experimental variable, the interposition of an extinction of the H-bar (plus a probably large sampling error on such small groups). Using this reasoning, the effect of interpolated extinction was to reduce the value at (5) by 23 responses, *i.e.*, 29 − 6 = 23. Means (6), (7), and (8) may be analysed in a similar manner.

It seems likely that the greater the number of responses on the first extinction, the greater will be the secondary-extinction effect. Means (1) and (5), (2) and (6), and (3) and (7) seem to show this effect, although (4) and (8) do not fall into line. Pavlov (**10**, p. 55) says on this point, "If the stronger reflex is subjected to primary experimental extinction, the weaker conditioned reflex undergoes complete secondary extinction." [5]

It becomes clear that, while the size of the secondary-extinction effect is about 63 percent, in order to predict in this experiment the mean responses for any one group that have followed a particular order of training and extinction, it would be necessary to have empirical values for at least four factors. The factors suggested are:

1. The relationship between number of reinforcements and responses during extinction. This should be known for both the easier response (H-bar) and the more difficult one (V-bar).

(2) The amount of 'positive generalization,' or transfer, during training, from one response to the other, both from harder to easier and the converse.

3. Interference with the first-learned response by the reaction learned later. The possible presence of this effect, as well as its size, would be determined for a more difficult reaction learned after an easier one and conversely.

[5] This complete secondary extinction was observed in only one case in this experiment. Rat no. 1 (Table II) gave 104 responses on the first extinction and none on the second.

4. The secondary-extinction effect between reaction-tendencies of different degrees of difficulty, *i.e.*, different degrees of strength, since a more difficult response is presumably less well learned after a given amount of training.

If a more general predictive system were desired, each of the above factors could, of course, be elaborated into two or more functions. It seems likely that the techniques presented and suggested in the present paper could be employed in such determinations.

Summary and Conclusions

1. Although secondary extinction is an accepted principle in conditioning, its presence has not been demonstrated in other sorts of learning. This experiment was designed as a test for the presence and size of this effect between two 'rewarded' responses of the type commonly found in problem-box learning.

2. Nineteen rats were divided into four groups. All rats were given forty training trials on each of two different responses, one of which was depressing a horizontal bar, the other, pushing sideways a vertical bar. Each operation of a bar was reinforced with a pellet of food. After training, all rats were given experimental extinction by non-reinforcement first on one bar, and five minutes later, on the other bar. Training and extinction orders were such that on each extinction all of the four possible training and extinction sequences were represented.

3. Because it was free-moving in the experimental situation, the rat itself determined the intervals between successive reinforcement and extinction responses. Since this was so, the progress of the acquisition of each response-tendency was indicated by the decrease in time necessary for the rats to make the twenty responses on each of the successive days of training. After training on one bar, learning to operate the second bar required less time than if there had been no previous training. This indicates a possible 'positive generalization,' or transfer.

4. *Comparison of the mean responses during the two extinctions revealed a decrease of 63 percent from the first to the*

second. The difference between the value at the first extinction, 43, and that at the second, 16, was reliable, the $\frac{\text{Dif.}}{\sigma\,\text{Dif.}}$ *being 4.23.*

5. While the secondary-extinction effect seems to be present, it is still impossible to predict the size of this effect for any one group of rats that have followed some particular training and extinction sequence. Before any such prediction can occur, it is necessary to have empirical values for at least four variables. These variables are defined and the probable direction of the influence of each is suggested.

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A STUDY OF HUMAN SALIVARY CONDITIONING[1]

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The theory of the conditioned response, based to a great extent upon Pavlov's (**10**) work on salivary conditioning in dogs, has been of utmost significance in the development of psychology. This theory is not only important in the field of learning, but it has had wide ramifications in most of the other fields of psychology. Pavlov's results have been accepted by many as the prototype of all learning, and a complex theoretical superstructure has been built upon the assumption that his findings are valid. At the same time, it is well known that many responses do not follow the laws which govern salivation. The salivary response itself varies among different animal species, and human salivation has seemed especially difficult to condition.

The present study is concerned with human salivary conditioning. A comparison of human and subhuman salivary conditioning is important for the theory of learning, and anything which throws some light on the nature of the conditioned response will be of value. By investigating the same response used by Pavlov, we can make important comparisons, study human behavior on a relatively simple level, and attain a better understanding of some core problems of conditioning, learning, and behavior in general.

History of Work on Human Salivation

There has been little work on salivary conditioning in adults, most of what has been done being concerned with the unconditioned response. Lashley (**7**) has summarized the

[1] The author wishes to express her thanks to Professor Hulsey Cason who suggested the problem and gave aid and encouragement throughout the progress of the research, to Mr. Melvin Bartell who assisted with the preliminary work, and to Mr. Delton Beier and Mr. Donald Krause who assisted with the main body of experimentation, statistical calculations, and analysis of data.

studies of human salivation up to 1915. He developed a suction tube to supplant the older methods of collecting saliva and carried out a more extensive study (**8**) than any of his predecessors. Winsor (**14, 17**) made a series of studies of the same problem.

Various reports of salivation at the thought, sight, or smell of food have been offered as evidence that a conditioned response had been established. Although Zebrowski (**19**), Brunacci (**1**), and Gley and Mendellsohn (**5**) found no such evidence for a conditioned salivary response, Lashley (**8**) and Winsor (**14, 15**) reported conditioned salivation in experimental situations in which the subject had formerly obtained food.

Experimental conditioning of the salivary response has in general been somewhat unsuccessful. Failures to condition this response have been reported by Gley and Mendellsohn (**5**), Richter and Wada (**13**), and Winsor (**15**). On the other hand, Krasnogorsky and other Russian workers since 1903 have obtained results with children which are similar to the results which Pavlov obtained with dogs (Krasnogorsky, **6**; Razran, **11**). Razran (**12**) has made an extensive and well-controlled study of human salivary conditioning, and he obtained sporadic conditioning with different subjects at different times, some facilitation of conditioning under definite instructions, and apparently some conditioning to words, nonsense syllables, and thoughts.

We followed Razran's (**12**) procedure in obtaining several measures of the amount of salivation before and after training in a number of subjects, but we did not attempt to control the subjects' attitudes as Razran had done. We wished to observe the effect of training on the variability as well as on the amount of salivation, and on the amount of salivation to the combined as well as to the substitute stimulus. In his study of the conditioned eyelid reaction, Cason (**2**) found that training may have a stabilizing effect on the eyelid response to combined stimulation of shock and sound. We wished not merely to study conditioning in the traditional sense of the term but to find out all we could about the effect of

different patterns of stimulation upon different aspects of the salivary response.

Procedure

Method of Measuring Salivation.—Razran's (12, 11–12) absorbent cotton technique was used in collecting the saliva. Johnson and Johnson No. 3 absorbent dental cotton rolls ($1\frac{1}{2} \times \frac{1}{2}''$) were cut in half to fit comfortably under the subject's tongue. The rolls of cotton were kept in numbered envelopes when not in use and were weighed in the envelopes beforehand, and again after each trial. The measure of salivation was the milligrams of saliva secreted in half-minute intervals of time.

Stimulating Conditions.—The control condition throughout the experiment was the amount of salivation to cotton alone ('C'). Cryst-O-Mint 'life savers' (over 99 percent sugar) were used as the original stimulus ('O'), and the sound of a buzzer directly over the subject's head was used as the substitute stimulus ('S'). Three subjects used citric acid tablets as the original stimulus, and inasmuch as their results were similar to those of the other subjects, all of the data have been combined in the group averages.

The original and substitute stimuli were present throughout the half-minute period during which the cotton was in the mouth. In the combined mint-buzzer stimulation, the buzzer was started as the subject put the cotton in his mouth, and he placed the mint on the tip of his tongue about two seconds afterwards.

By subtracting the amount of salivation to cotton alone (C) from that to cotton plus mint (OC) and cotton plus mint plus buzzer (OSC), the effects of the original stimulus (O) and of combined stimulation (OS) were found. By subtracting the amount of salivation to cotton alone from that to cotton plus buzzer (SC), the effect (S_1) of adding the substitute stimulus to cotton was found. By subtracting the amount of salivation to the mint (OC or O) from that to mint plus buzzer (OSC or OS), the effect (S_2) of adding the substitute to the original stimulus was found.

Experimental and Control Sessions.—The experimental session for each subject was two hours long, and there were 72 successive half-minute trials. The intervals between trials were 50, 55, 60, or 65 seconds. There were three two-minute rest periods, and the subject was given a drink of water during the second rest period.

The experimental session included a pre-training, training, and post-training series. The pre- and post-training series were exactly the same, and in each of these series, six measures were obtained for each of the four stimulating conditions (C, SC, OC, OSC). A comparison of these two series shows the effect of training, and the difference between salivation to cotton alone in the pre- and post-training series serves as a control to which the effects of training on salivation to the other stimuli may be compared.

A regular experiment and a control experiment were carried out. For the experimental group of 13 subjects, the training series consisted of 24 trials in which C and OSC were alternated; for the control group of 5 subjects, C and OC were alternated. All of the experimental conditions were kept constant except the association between S and O, and any differences between the results of the two groups should be due to this association.

Experimental Precautions.—The 50- to 65-second intervals between trials and the various stimuli and groups of stimuli were rotated in a controlled order. The number of amperes in the circuit operating the buzzer was kept constant, and general environmental conditions were kept as quiet and as constant as possible. Instructions to the subject were given by means of a simple code of clicks, with a three-second warning before the cotton was to be put in or taken out of the mouth. The instructions which

were given at the beginning of the session were designed to minimize tenseness and disturbing movements. The subject swallowed before each trial to remove any excess saliva. The time of day and the length of time after eating were different for different subjects, but examination of our results did not show that these factors had any effect. The 18 subjects used were college students taking their first course in psychology, and they were almost completely naive.

It is possible that the six tests of salivation to combined stimulation (OSC) in the pre-training series were themselves sufficient to establish a conditioned salivary response to the buzzer (SC) before the beginning of the regular training series, and if this were the case, our measures of salivation to the buzzer before training would not be valid. Because of these considerations, a preliminary control experiment was carried out, using seven subjects. In this experiment, OSC was omitted in the pre- and post-training series, and the training series was limited to one, two, or three repetitions of OSC. No conditioned salivary response to the buzzer was established with one, two, or three training repetitions of OSC, and it is therefore reasonable to assume that no conditioned response to the buzzer would be established in the pre-training series of our main experiment.

Results

Treatment of Results.—The Median of the 24 trials of each subject's salivation to cotton alone throughout the whole experimental session was first obtained. The secretion for each trial during the experiment was then expressed as a percentage deviation from each individual's Median salivation score. In this way each subject's results were weighted equally in the group averages.

The results of all of the subjects were combined to show whether or not the results as a whole favored conditioning. The absence of a group indication of conditioning would not show that some conditioning had not occurred in individual subjects, but since the individual results were based on a limited number of measures, a group measure seemed advisable.

Group Averages.—The principle results of the experiment are given in Table I. The figures in the table are percentage deviations from the individuals' Median salivation scores. Each figure for the experimental group of subjects is the average of 78 measures from 13 subjects, and each figure for the control group of subjects is the average of 30 measures from 5 subjects. Columns C, SC, OC, and OSC show the amounts of salivation to cotton alone, cotton and substitute stimulus, cotton and original stimulus, and cotton and

combined stimulation, respectively. Column S_1 shows the effect on salivation of adding the substitute stimulus to cotton, column O the effect of adding the original stimulus to cotton, column OS the effect of adding combined stimulation to cotton. The figures in each of these three columns were obtained by subtracting the amount of salivation to cotton alone from that to the various combinations of stimuli. The last column (S_2) shows the effect on salivation of adding the substitute to the original stimulus, obtained by subtracting the amount of salivation to the original stimulus alone from the amount of salivation to original plus substitute stimulus (OSC − OC, or OS − O).

TABLE I

AVERAGE PERCENTAGE DEVIATION FROM INDIVIDUAL MEDIAN SALIVATION SCORES (GROUP AVERAGES)

	Pre-Training							
	C	SC	OC	OSC	SC–C (S_1)	OC–C (O)	OSC–C (OS)	OSC–OC (OS–O) (S_2)
Experimental.....	−8	−7	+89	+79	+1	+97	+87	−10
Control.....	−1	−8	+98	+96	−7	+99	+97	− 2
	Post-Training Minus Pre-Training							
	C	SC	OC	OSC	SC–C (S_1)	OC–C (O)	OSC–C (OS)	OSC–OC (OS–O) (S_2)
Experimental.....	+30	+19	+19	+51	−11	−11	+21	+32
Control.....	+20	+26	+25	+20	+ 6	+ 5	0	− 5

The figures for the pre-training series show the effects of the various stimuli or combinations of stimuli before training. Before training, salivation to cotton alone (C) or to cotton plus buzzer (SC) was about the same or slightly less than the individual Median salivation score. Salivation to cotton plus mint (OC) or to cotton plus mint plus buzzer (OSC) was from 79 percent to 98 percent more than the individual Median salivation score. Columns S_1 and S_2 show that adding the buzzer to cotton alone or to cotton plus mint had no appreciable effect on salivation, that is to say, the effect

of the substitute stimulus was neutral before training. Inasmuch as the figures for the experimental and control groups are approximately the same, any differences between the experimental and control groups after training should show the effects of the different kinds of training.

The results for the post-training series are not shown, but instead we have listed the differences between the pre- and post-training series, which show the effects of training. The lower half of Table I shows that after training there was a striking increase in salivation to cotton alone in both the experimental and control groups. In the control group, salivation to SC, OC, and OSC increased approximately the same as salivation to cotton, but in the experimental group there was a smaller increase to SC and OC and a considerably greater increase to OSC. These results suggest that training with combined stimulation had a differential effect upon the reactions to the different stimuli, increasing the effect of combined stimulation (OSC) and decreasing the effect of both SC and OC. The effect of training on salivation to the substitute stimulus was different when S was combined with C and when S was combined with OC. Salivation to S was decreased when S was combined with C and increased when S was combined with OC.

Results of Individual Subjects.—Table II shows the per-

TABLE II

PERCENTAGE OF INDIVIDUAL SUBJECTS GIVING RESULTS IN THE SAME DIRECTION AS THE EXPERIMENTAL GROUP

Stimulus	C	S_1	O	OS	S_2
Average percentage deviation from individual median salivation scores of experimental group, post-training minus pre-training (Data from Table I)	+30	−11	−11	+21	+32
Percentage of individual subjects in the experimental group (N = 13) whose median result was in the same direction (Algebraic sign the same) as the result shown above in the second row	77	62	31	62	62
Percentage of individual subjects in the control group (N = 5) whose median result was in the same direction (Algebraic sign the same) as the result shown above in the second row	60	60	20	40	20

centage of individual subjects giving results in the same direction as the experimental group. The first row gives the stimulus, and the second row shows the effect of training in the experimental group. The third row shows for the experimental group, and the fourth row shows for the control group, the percentage of individual subjects whose Median results were in the same direction as the results of the experimental group.

It is evident that there was considerable individual variation, because the results of many individual subjects were in the opposite direction from the group averages. The group results of Table I are therefore not entirely reliable, and it appears that uncontrolled factors must have had some influence on the individual results.

The results shown in the third and fourth rows of Table II are also not entirely consistent. As shown in the second row of Table II, there was a decrease in salivation to S_1 and to O in the experimental group, but this decrease was found in as large a percentage of subjects in the control group as in the experimental group. The decrease in salivation was therefore not the result of the training alone.

Column OS in Table II shows, however, that the training did have an effect on salivation to OS. Salivation to OS was more often increased after training in the experimental group, whereas it was more often decreased after training in the control group. The post-training minus pre-training figures for OS are positive for 62 percent of the subjects in the experimental group and for 40 percent of the subjects in the control group. Column S_2 in Table II shows that training had a similar effect on salivation to S_2. The post-training minus pre-training figures for S_2 are positive for 62 percent of the subjects in the experimental group and for 20 percent of the subjects in the control group.

Median Deviations in Salivation.—Table III summarizes the variability of salivation under the different stimulating conditions. The first four columns, pre-training series, show the absolute Median amounts of deviation (C, SC, OC, OSC), and the last four columns show the Median differences ob-

tained by adding various stimuli to cotton, or in the case of S_2, by adding the substitute stimulus to the combination of cotton plus original stimulus. The first four columns, post-training minus pre-training, show the differences in gross salivation obtained by training, and the last four columns show the differences between the effects of the various components of stimulation before training and their effects after training.

In obtaining the figures shown in Table III, (1) we calculated for each subject the Median amount of salivation to each stimulus and to each combination of stimuli (C, SC, OC,

TABLE III

MEDIAN DEVIATIONS IN SALIVATION

	Pre-Training							
	C	SC	OC	OSC	SC–C (S_1)	OC–C (O)	OSC–C (OS)	OSC–OC (OS–O) (S_2)
Experimental.....	16	17	42	30	+2	+21	+10	+9
Control.....	16	32	28	30	+6	+ 9	+12	+2
	Post-Training Minus Pre-Training							
	C	SC	OC	OSC	SC–C (S_1)	OC–C (O)	OSC–C (OS)	OSC–OC (OS–O) (S_2)
Experimental.....	+3	+7	+6	+4	+ 4	− 4	+ 2	+ 8
Control.....	+1	−5	−3	+9	−14	−17	+12	+21

and OSC) before and after training; (2) we calculated for each subject the Median deviation from the Median amounts of salivation referred to in (1); (3) for the whole group we found the Median before training of these individual Median deviations (columns C, SC, OC, and OSC, pre-training); (4) we found for each subject the differences between his Median deviations in salivation to C, on the one hand, and to SC, OC, and OSC, on the other, and the difference between his Median deviation to OSC and OC, or to OS and O; (5) for the group as a whole we found the Median of the differences referred to in (4) (columns S_1, O, OS, and S_2, pre-training); (6) we found for each subject the differences between the pre-

and post-training figures referred to in (2) and (4); and (7) we found the Median of the differences between pre- and post-training for the group as a whole, as shown in the lower half of Table II, post-training minus pre-training.

Before training, the Median amount of variation around the different subjects' Median salivation to cotton alone (C) was 16 percent of the individual Median salivation scores for both the experimental and control groups. The Median deviation of salivation to cotton plus substitute stimulus (SC) was 17 percent of the individual Median salivation scores for the experimental group and 32 percent for the control group, the Median difference (S_1) between deviation to cotton plus substitute stimulus and to cotton alone being two percent and six percent. The Median deviations to cotton plus original stimulus (OC) were 42 percent and 28 percent, the Median differences obtained by adding the original stimulus (O) to cotton alone being 21 percent and 9 percent of the individual Median salivation scores. The Median deviation to cotton plus combined stimulation (OSC) was 30 percent of the individual Median salivation scores for both groups. The effect of adding the substitute stimulus to the original stimulus was to increase one Median slightly and to decrease the other (OS compared with O), and the Median effect (S_2) was a very slight increase in variability for both groups.

The figures in the lower half of Table III show that the effect of training upon variability was slight. All of the differences between post-training and pre-training were small compared with the absolute amount of variability before training. In the experimental group, there were no significant differences between variability before and after training. In the control group, variability to the substitute stimulus (S_1) and to the original stimulus (O) was less after training, the Median differences being − 14 percent and − 17 percent of the individual Median salivation scores. The variability to combined stimulation (OS) was increased by two percent and 12 percent of the individual Median salivation scores. Although the differences between the experimental and control groups are slight, the differences obtained for O and OS suggest that the training had a stabilizing effect in both cases.

Discussion

In the experiment which we have described, no conditioning in the usual sense of the term was obtained. Salivation to the substitute stimulus was in most cases not increased after association with the original stimulus. We did find some effects which seemed to be due to this association: salivation to combined stimulation was increased after training with combined stimulation, while salivation to either stimulus alone was, if anything, slightly decreased. Even such a response as salivation apparently does not occur in a simple summative way, the effect of any given component of stimulation depending upon other stimuli within the total situation of which it is a part.

The same possibility of a differential effect of training upon the effects of a complex stimulating situation and its components was found with regard to variability. The variability of a response may be just as significant as its central tendency, and the response should be examined in all its different aspects. Zener (**20**) has recently emphasized the importance of behavior accompanying the conditioned response and the fact that this response is a dependent component in a complex, organized act. Like the pattern of stimulation, the pattern of response is not a simple combination of independent elements.

It has been seen that we were unable to establish a conditioned salivary response of the sort which Pavlov obtained in his dogs. One possible reason may be that our training series of twelve combined stimulations was not long enough. But in the face of the fact that so much human learning occurs in only a single trial, it is probable that this is not the whole explanation.

Another more probable explanation is that the failure to obtain a conditioned salivary response was due to the important role of set, attitude, and verbal activities in human learning. Cason (**3**, **4**) has emphasized the importance of verbal activities in learning, Lenz (**9**) has discussed the necessity of comparing conscious and objective processes, and Razran (**12**) was able to obtain consistent positive and

negative conditioning in human adults by establishing appropriate attitudes through verbal instructions. We obtained introspections from the ten subjects in the experimental group who used Cryst-O-Mints, and only two of them thought that the combination of mint and buzzer might lead to an increase in salivation to the buzzer alone. These subjects were two of the three for whom training actually increased salivation to the buzzer. The salivary response is generally considered to be relatively free from central or 'voluntary' control, and yet it appears that we succeeded in establishing a conditioned response when there was a favorable central set and failed to do so when such a set was lacking.

Another possible explanation is to be found in the nature of our experimental procedure. Since warnings were given by means of clicks 10 seconds before each trial, the subject always knew beforehand whether he was to have the mint or not, and the clicks themselves may have acted as substitute stimuli produced by verbal instructions in one or two trials. We may have been forming a differential conditioned response to the clicks, two clicks signifying 'mint' and leading to increased salivation, one click signifying 'no mint' and acting to decrease salivation.

One aspect of our results which requires mention is the great increase in salivation to cotton alone after training in both the experimental and control groups. Cotton alone may not have been as adequate a control as we assumed, and special factors which complicated our results may in part account for our failure to condition the salivary response.

Although our results are not entirely reliable, they indicate a complexity of stimulation and response in need of further analysis. We seem to have here a simple technique for analytic work: stimulation is easily varied and the response readily quantified, offering a point of attack upon some of the basic problems of conditioning.

Summary and Conclusions

The present investigation was a study of human salivary conditioning, and we were interested in comparing our results with those which Pavlov obtained on dogs.

Razran's absorbent cotton technique was used to collect the saliva, and measures were taken, before and after training, of salivation to cotton alone (the control), to the original stimulus (a Cryst-O-Mint life saver), to the substitute stimulus (the sound of a buzzer), and to combined stimulation. The training series consisted of 12 trials of combined stimulation alternating with cotton alone, and a control experiment was carried out in which the substitute stimulus was omitted from the training series.

The principal results of the study were as follows:

1. Our attempt to condition the human salivary response to the sound of a buzzer was generally unsuccessful. A majority of the subjects salivated slightly less to the buzzer after it had been presented with the Cryst-O-Mint, and the proportion of subjects who salivated more to the buzzer was about the same in the experimental group as in the control group.

2. Training with combined stimulation increased salivation to the combined stimulation, but it did not increase salivation to either the mint or the buzzer alone. Training with the original stimulus (control group) had no such differential effect.

3. The salivary response was found to be highly variable. Individual subjects varied from trial to trial, and the effect of various stimuli, in combination and succession, varied from subject to subject.

4. It is possible that the experimental and control procedures had differential effects on the variability of the salivary response. Training with combined stimulation had no apparent effect, but training with the original stimulus seemed to decrease variability to both the original and substitute stimuli and to increase variability to the original and substitute stimuli given in combination.

5. Our results in general indicate the need for a further analytical study of the pattern of stimuli and the pattern of responses involved in human salivary conditioning.

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REFINEMENTS IN TECHNIQUE FOR THE CONDITIONING OF MOTOR REFLEXES IN DOGS *

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I. Introduction

Since the early experiments on conditioned reflexes by the Russians, many improvements in technique have been introduced. As in other fields of scientific endeavor, these improvements have often led to new and more precise observations. Pavlov himself felt that great progress had been made when he moved to his soundproof laboratory which eliminated the effect of undesirable and distracting stimuli. Other advances have come from better methods of recording the responses and from new and more delicate procedures for operating upon animal preparations.

The program of research now under way at the Indiana Conditioning Laboratory has recently necessitated the development of a number of special techniques related to the problem of conditioning, and the standardizing of certain methods of handling animals, producing stimuli, and recording responses. It has seemed wise to make some formal record of these methods, both for the reference use of the laboratory itself, and for the benefit of research workers in other places who may find them of value.

II. General Handling of Subjects

Laboratory Treatment.—Dogs only have been used as subjects to date. We have found it advisable, in common with other investigators in this field, to concentrate on young animals. The dogs are mongrels of medium large size (20–

* The developments outlined in this publication from the Indiana Conditioning Laboratory were made possible by a series of grants-in-aid of research from the University.

40 lbs.) which are purchased from orthodox dog dealers who supply hospitals and medical research centers. We obtain our animals from foreign sources, so as to avoid any possible misunderstanding with local dog owners. Each dog is given an identification number in terms of which its laboratory history and ultimate disposition are recorded. Upon entering the laboratory, it is immediately weighed, deloused by dipping, and bathed. As soon as the animal is dry it is devocalized. This procedure is followed with all specimens upon the day of entry.

The animals are fed once daily, a prepared commercial dog food in hard cubes, containing cod liver oil, bone meal, and 26 other ingredients. Occasionally this diet is supplemented with a little canned salmon. At the termination of experiments, the dogs are either given away or painlessly killed by deep Nembutal anesthesia followed by intracardiac injections of ether.

Surgery.—All operations are performed under full surgical anesthesia. A rigid aseptic technique, like that employed in human surgery, reduces the number of postoperative infections. Nembutal is used for short operations such as devocalizing, but ether is preferred for longer and more difficult procedures. One and one half hours before anesthetization with ether, morphine sulphate (0.015–0.030 gm.) and atropine sulphate (0.0005–0.001 gm.) are administered subcutaneously. This reduces the quantity of ether needed and permits the employment of a Kunde mask for the administration of the ether during the operation. The mask in turn removes the necessity of a tracheotomy or the use of a close-fitting tracheal catheter.

Operations upon the nervous system are followed by careful neurological examinations and any animal is discarded which shows the effect of unintentional damage. A postmortem examination is made at the termination of the experimental work on any particular preparation, whenever it is considered essential.

The Experimental Situation.—For conditioning itself, the animals are strapped securely but loosely in a wooden stock,

located on a table in a small soundproofed chamber, 5 × 7 feet (see Fig. 1). They are trained entirely in this chamber, in complete isolation from the experimenter or other disturbing influences. Observations of their general behavior can be made through two large triple-glass windows, which permit one-way vision only. Automatic recording systems (*vide infra*) produce graphic tracings (in the experimenter's room outside the soundproofed chamber) of the responses of the foot or feet being tested, and of respiration. The soundproofed room is electrically insulated for work with action potentials.[1] No subject is used in conditioning experiments until he has been in the laboratory at least a week, has thoroughly recovered from the devocalizing operation, and has become adjusted to the food and laboratory routine.

III. Conditioned and Unconditioned Stimuli

Shock Stimuli.—For an original or unconditioned stimulus we have employed either direct current or 60 cycle a.c. If alternating current is used, the duration of the shock is .2 sec. With d.c., a single make and a single break have been found effective, separated by a .2 sec. interval. The use of grills or grids on which the animal rests his feet are not satisfactory as a means of contacting the subject because he may return his foot to the shocking surface in a different way after each flexion response. We have found it better to tape small electrodes to the clipped anterior and posterior surfaces of the paw just below the wrist or ankle.[2] The electrodes are stainless steel discs 2 cm in diameter.

An animal can escape or avoid the shock by lifting his foot to a predetermined height before the shock arrives. This action throws a small mercury switch mounted on the recording lever which breaks the shock circuit. But if a dog is slow in raising his foot on any particular trial, it is not always possible to tell by general observation, or from the record of

[1] For a general description, with floor plan, of the Indiana Conditioning Laboratory, see Kellogg, W. N., The Indiana Conditioning Laboratory. *Amer. J. Psychol.*, 1938, 51, 174–176.

[2] *Cf.* Forbes, T. W., Muenzinger, K. F., Wendt, G. R., and others, Report of Round Tables on the use of electric shock. *Psychol. Bull.*, 1935, 32, 185–196.

the flexion response, whether he received or escaped the shock. In such cases his response may be either an unconditioned reflex to the shock, or an anticipatory response of long latency made to the conditioned stimulus preceding the shock. The most effective device which we have found to differentiate between these two possibilities is a continuous record of the respiration. Pneumographic records obtained during all conditioning experiments show whether unconditioned gasping produced by the shock is present. If the breathing record is smooth at the instant the shock should have been received, then the dog was not shocked. A sharp deflection in the record indicates that the shock was delivered.

According to our observations, the best criterion for adjusting the intensity of the shock is a behavioral one. Changes of resistance in the same dog on different days, or even within the same experimental period, make resistance measures of only temporary value. As a result our animals are tested with shock alone before each conditioning period, to determine what potentiometer adjustment is just sufficient to produce a rapid withdrawal to the maximum height permitted by the apparatus. The d.c. voltage across the electrodes can then be read from a voltmeter permanently in circuit.

A small signal-light located on the experimenter's instrument table is placed in parallel with the main leads of the shock circuit. Whenever a shock is sent to the subject's foot, the light lights. This signal serves not only as a check on the shock mechanism, but permits observations of the subject's behavior at the instant the shock occurs.

Conditioned Stimuli.—For conditioned stimuli we have employed (1) a 1000~ tone from an audio-oscillator delivered through a loud speaker about 2 feet above the dog's head, (2) the sound of a doorbell buzzer of approximately the same intensity located at nearly the same point, (3) light from 75 watt bulbs in front of and below the dog's head, in easy line of vision. The sound stimuli which would be inaudible to the experimenter because they are produced in the soundproofed chamber, can be heard through an earphone in parallel with

the stimulus circuit. Separate adjustment of the intensity of the sound in the earphone can be made without affecting the loudness of the stimulus produced by the speaker. The intensity of the sound stimuli received by the experimental animals has been kept within the medium range, since none of the work of the laboratory has thus far been concerned with the study of thresholds or other sensory phenomena. Our 1000~ tone, at the position of the dogs' ears, is 50–55 decibels above the human threshold.

The Timing of the Stimuli.—Both conditioned and unconditioned stimuli are automatically timed by a special pendulum timer. A trip on the bottom of the pendulum bob activates a series of mercury switches, arranged along the arc of swing, which appropriately make and break the necessary circuits. The timing adopted as most satisfactory is essentially that in use at other laboratories. The conditioned stimulus lasts for 2 full seconds, and the unconditioned shock coincides with the last .2 sec. of the 2-sec. period. Each trial consists therefore of 1.8 sec. of conditioned stimulation and .2 sec. in which the conditioned and unconditioned stimuli occur simultaneously.

IV. Recording the Response

Three kinds of conditioned responses have been subject to quantitative study in our laboratory. These are the conditioned flexion response, conditioned muscular tensions recorded by action potentials, and conditioned breathing.

Pneumatic Registration.—The method of recording the flexion response which was finally adopted is illustrated in Fig. 2. The foot of the dog is strapped to the end of a balanced wooden lever (*BC* in Fig. 2) 12 inches in length. The fulcrum, *D*, is approximately at the middle of the lever. When the animal lifts his foot this depresses the more distant end of the lever which presently encounters a bumper so as to limit the height of lift to approximately 4 inches. Early attempts were made to attach threads or cords to this lever as a means of recording the response. The threads were run through a series of glass pulleys to muscle levers which marked against

a kymographic drum. This method did not prove accurate, however, and was subsequently abandoned in favor of the pneumatic system illustrated.

DE (Fig. 2) is a lever arm of the recording system mounted so that it is slightly eccentric to the bar *XY*. When the end of the recording arm at *D* is raised, this depresses the end at *E* by an amount determined by the size of the angle *CDE*. A

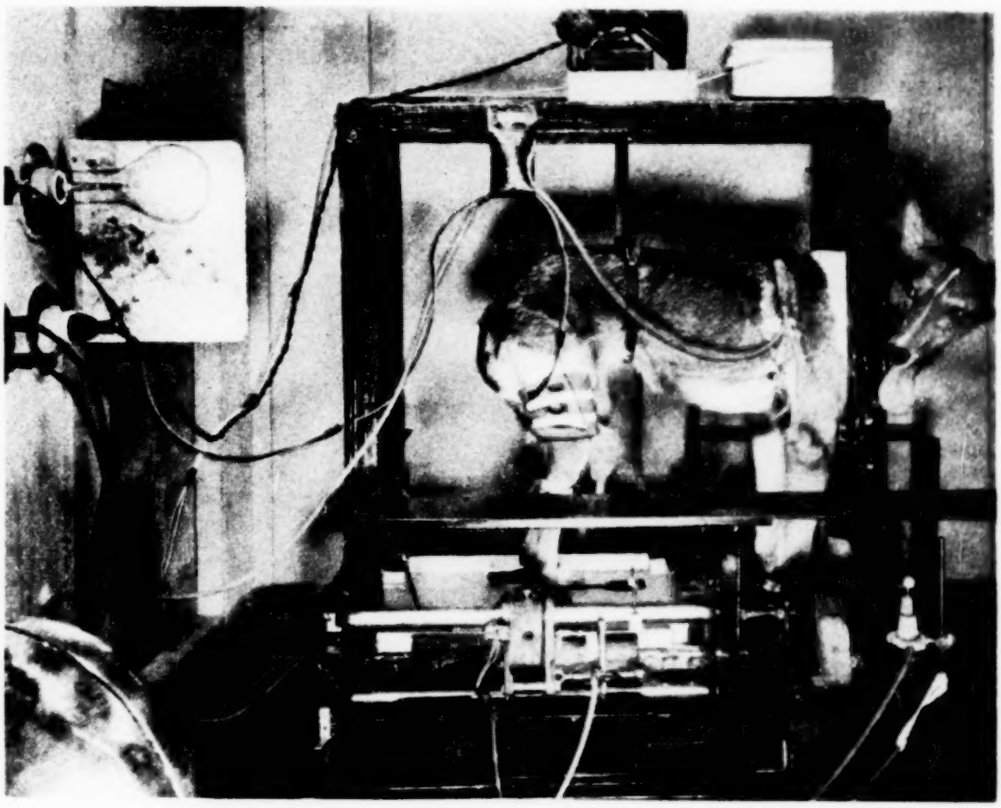

FIG. 1. Showing stock and accessory equipment for taking simultaneous records of the responses of all 4 feet, the respiration, and action potentials of the right hind leg.

nail at *E* presses down upon a cork fastened in the end, *G*, of the smaller lever *FG*, the fulcrum of which is at *F*. By adjusting the position of the tambour, *H*, at different points along the lever *FG*, marks of different height on the kymographic tracing can be produced by a constant lift of the lever *BC*. The entire mechanism can be moved back and forth along the bar *XY*, so as to fit the apparatus to the dimensions of different sized dogs. This method has proven highly

satisfactory in recording something over 20,000 flexion responses of all 4 feet, made by a considerable number of animals.

Electrical Registration.—Localized action potentials as a means of measuring the response have also been taken—

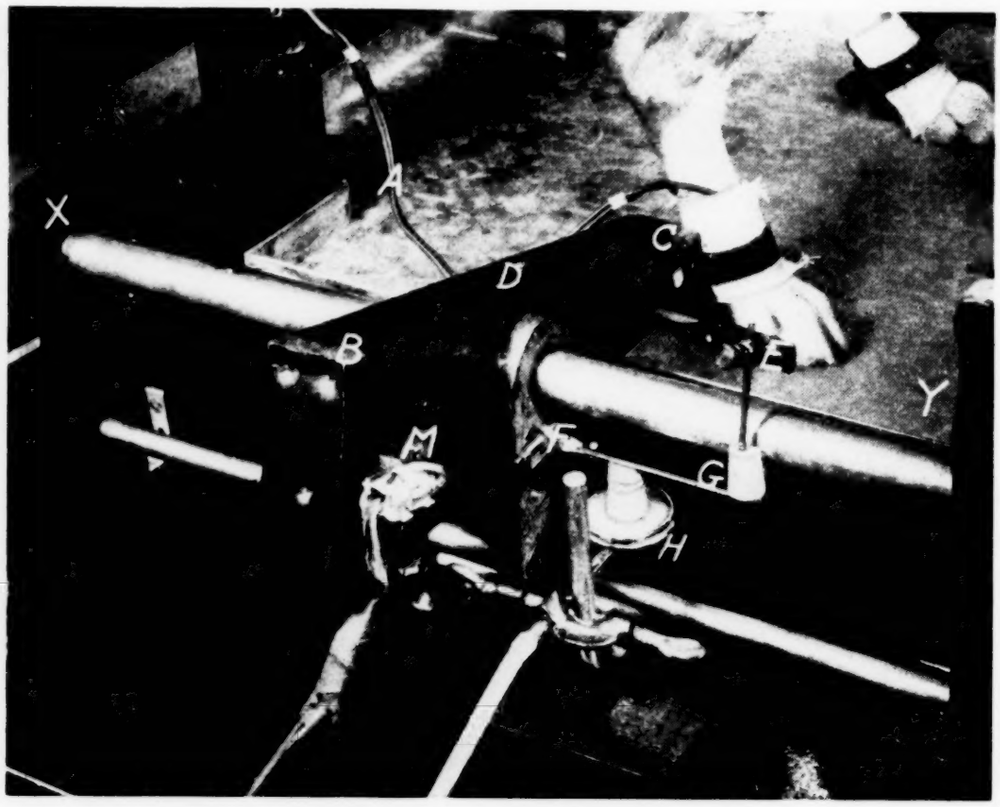

FIG. 2. The recording mechanism for flexion response. *BC* is a balanced lever 12 inches long which can be adjusted along the heavy bar *XY* so as to accommodate animals of different size. The wires, *A*, by means of which the shock stimuli are transmitted, go to the electrodes which are fastened beneath the pad which protects the dog's foot from the strap at *C*. *DE* is the arm of the recording mechanism which is set a little eccentric to the bar *XY*. When the lever *BC* is raised at *C*, the nail at *E* depresses the cork at *G* on the smaller lever *FG*, which has a fulcrum at *F*. By sliding the tambour and cork, *H*, along the lever *FG*, a kymographic recording of any amplitude can be obtained from a fixed movement at *C*. The mercury switch, *M*, breaks the shock circuit when *C* is raised to a sufficient height.

from both fore and hind legs. A cathode ray oscillograph and high speed moving film camera are used to record the response. The active electrode is fastened to the shaved surface of the dog's leg by means of adhesive tape. The inactive electrode is similarly fastened to a heavy pad satu-

rated with normal-salt solution. For foreleg recording the inactive electrode is placed above the elbow over MMs. *triceps brachii* and *brachialis*. The active electrode is placed on the lateral surface about 2 inches below the elbow over M. *extensor digitorum communis* and M. *extensor carpi radialis*. In taking action potentials from the hind leg, the inactive electrode is fastened above the knee across MMs. *biceps femoris* and *semitendinosus*. The active electrode is put on the lateral surface below the knee, approximately over MMs. *tibialis anterior* and *peroneus longus*.

The mechanical and electrical systems can be synchronized through a common timing device which transmits fifth-second time intervals to each system simultaneously. Further synchronization is accomplished by having signal markers which record stimuli upon the kymograph, in circuit with other markers which simultaneously expose light signals which are in turn photographed upon the oscillographic records.

Pneumographic Registration.—A Sumner pneumograph like that generally used with human subjects has been found an excellent device for recording respiration in dogs. If the animal is large enough about the chest, the pneumograph can be fastened exactly as it is upon a human. In studies of conditioned breathing, it has been our practice to attach the pneumograph about the thorax immediately behind the forelegs.

By combining these different devices it has been possible to get as many as 6 simultaneous records from a single subject. These include the movements of all 4 feet, the tensions of a particular muscle group, and respiration.

V. Measurement of the Response-Records

The Flexion Response.—Measurements of the recorded response are made with the aid of mechanical drawing instruments, a magnifying glass when this is necessary, and with special devices to be described. The transcribed record of a sample response which will illustrate the procedure for the flexion *CR* is reproduced in Fig. 3. The conditioned part of

the response is that which occurs in the buzz-period before the shock has been given. It is interrupted by the unconditioned reaction in this instance, because the subject did not raise his foot high enough to activate the mercury switch and so escape the shock. The latency of the response is indicated by the distance from *A* to *L* in the drawing. The duration of the conditioned response up to the moment of its interrup-

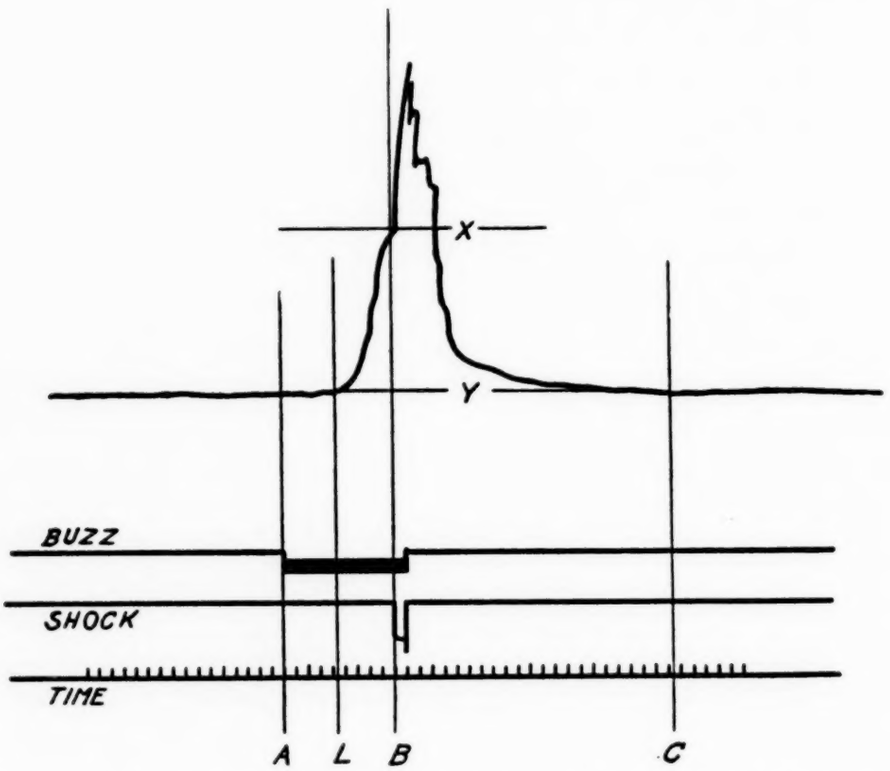

FIG. 3. Transcript of a typical dual response. The conditioned lift to the buzz which extends from *L* to *B* is interrupted by the unconditioned withdrawal. In this sort of a reaction the subject has not raised his foot high enough to escape the shock. The latency is measured from *A* to *L* and the duration of the interrupted *CR* from *L* to *B*. The total duration of the dual reaction is *LC*, while the amplitude or height is the distance *XY*. Time units are in .2 sec.

tion by the unconditioned, is *LB*, while the duration of the total combinational reaction would be measured from *L* to *C*. The amplitude of the conditioned response is commonly measured either at the point of shock, along the line *B*, or at the highest deflection of the response from the horizontal baseline *Y*. In the example pictured, these two measures of amplitude would be the same. Beside latency, duration, and

amplitude, the other attributes of the flexion *CR* which can be made the subject of study are the relative frequency, or the number of responses occurring to a given number of stimulations, the contour or configuration of the *CR*, and the rate or speed of lift. [3]

The Electrical Response.—To measure records of conditioned behavior obtained by means of action potentials, the oscillographic photograph is first divided into convenient small time units of, say 1/12 sec., by reference to its time markings. Horizontal lines are drawn tangent to the maximum and minimum peaks in each section and the distance between them is measured in units of .02 inch. Such measurements are then averaged over the time critical for the response. This gives a value which seems to represent the amount of muscular activity rather well. The significance of the measure will usually depend upon a comparison of the activity during the critical period for the response, with the activity during some period of about the same length when no stimulus is delivered. In this way the effect of continuous activity like struggle or repeated barking can be discounted. The comparison may be made either by expressing the response measures as a percentage of the activity in the quiet period, or by taking the difference between the two.[4]

The Pneumographic Response.—Conditioned respiration has been quantitatively analyzed by tracing the pneumographic records before and during conditioned stimulation with a graphometer.[5] This instrument is essentially a combination of two planimetric units with special ratchet attachments. By following the wavy line to be measured with the

[3] Some special relationships between these measures have been discussed by Kellogg, W. N. and Walker, E. L., An analysis of the bilateral transfer of conditioning in dogs, in terms of the frequency, amplitude, and latency of the responses. *J. Gen. Psychol.*, 1938, **18**, 253–265. Illustrations of different types of contours will be found in Kellogg, W. N., Evidence for both stimulus-substitution and original anticipatory responses in the conditioning of dogs. *J. Exper. Psychol.*, 1938, **22**, 186–192.

[4] This method is fundamentally an adaptation of that used by Davis for human subjects. *Cf.* Davis, R. C., The relation of certain muscular action potentials to mental work. *I. U. Science Series*, 1937, No. 5, 1–29.

[5] Kellogg, W. N., A device for measuring kymographic records. *J. Exper. Psychol.*, 1936, **19**, 383–385.

index point of the graphometer, the vertical oscillations made from a horizontal baseline will be automatically summated. When breathing curves are traced in this manner, the result is a graphometer record of the total breathing activity which transpires within the time interval measured. The practice in our laboratory has been to consider a breathing change as definitely conditioned, when the graphometer reading for the breathing which occurred while the conditioned stimulus was in process of being presented, is significantly different from the pre-stimulation breathing.

VI. Habituation and Procedure

Methods of Habituating.—Tests as to the optimum amount of time desirable for habituating an animal to the stock and other apparatus have yielded somewhat conflicting results. When it is necessary to fasten a great deal of special equipment directly to the body of the subject, these extra attachments probably tend to make habituation to the whole situation increasingly difficult. Some accessory apparatus is almost always necessary, but in certain experiments there is more of it than in others. Tape, bandages, electrodes and other parts which must be attached to the animal are placed there before he is taken to the soundproofed experimental room. Our practice has been to place the subject upon a table and wrap a cloth or blindfold around his muzzle so as to cover up his eyes while he is being prepared. After a few repetitions of this treatment most dogs will remain prone upon the preparation table without movement, even though experimenter and assistants talk aloud and walk freely about the room.

The elimination of struggling in the confining situation of the stock is a problem which is not easy to solve. We have found it impossible to eradicate this behavior by simply placing the subject in the stock without other stimulation, or by feeding him in the stock. Such a method may work with some specimens, but it has not worked, in our experience, with all. In one case an animal was given 14 daily habituating periods of 20 minutes each, with no evident decrease in the spontene-

ous struggle responses that he made. A dog may occasionally do himself serious bodily harm as a result of his efforts to escape from the apparatus. The confining straps and collar seem to be potent stimuli in this connection.

Another important factor in inducing struggling is the intensity of the electrical stimulation given. This, of course, is always a relative intensity which depends upon the particular sensitivity of the animal. The most quiet and docile specimen can be made to struggle by increasing the shock which he receives. Probably the Yerkes-Dodson Law is applicable here, in the case of conditioning, as it is in other sorts of learning. At any rate, there seems to be such a thing as a threshold of struggle, or a threshold of tolerance, for every animal. If the shock is adjusted low enough, the subject will not struggle, but if it is increased too much it may go beyond his threshold of struggle or threshold of tolerance. When the threshold of tolerance is below the threshold for making an unconditioned flexion withdrawal, then the subject may struggle before (or in the process of) making an unconditioned flexion response. Under such circumstances it may be difficult to get adaptive conditioning of a particular member, uncomplicated by struggling. For the struggling is likely to become so definite a part of the behavior pattern that it will not drop out even with long training.

Despite these difficulties, the majority of our animals seem to become fairly well habituated to the stock and necessary attachments after 4 daily periods of about 20 minutes each. We have used this habituating sequence more than any other. During the first period the experimenter remains with the dog, but in later periods he leaves the soundproofed room and closes the doors, observing the animal only through the one-way-vision windows.

Conditioning Procedure.—The first trials—commonly given on the fifth day—are control trials with conditioned stimulus alone. Then follows the regular process of conditioning which continues in daily sessions or series of 20 trials each. A small proportion of these 20 trials are usually control trials in which the shock is omitted. Omissions of the shock stimu-

lus have been made on the last trial in each daily series, on every tenth trial, or at more frequent and irregular intervals. There may be no omissions at all, except those that are introduced by the animal himself when he lifts his paw high enough to escape the shock. Omissions are not necessary to measure the progress of conditioning, since any lift occurring in the buzz period before the shock is a conditioned response. Successive buzz-shock stimulations are spaced at irregular intervals varying from 15 to 120 secs., so that a daily series of 20 trials consumes about 20 minutes or slightly less.

These fundamentals of daily procedure have needed little modification when applied to experiments with widely varying objectives. Under the technique outlined normal animals will become pretty well trained to give simple flexion responses after 10 days of training, or in a total of 200 conditioning trials. Of course it may be necessary to give many more trials, depending on the purpose of the investigation, the nature of the conditioning, the criterion of learning, and the individual subject. Some of our dogs have currently received more than 1000 trials in 50 separate conditioning sessions.

VII. Summary

The object of this paper has been to make some record of the technical and experimental refinements in methods of conditioning motor reflexes in dogs, which have recently come into use in the Indiana Conditioning Laboratory. The flexion response, reactions of certain muscle groups and conditioned respiration have been discussed. Following are some of the developments reported.

1. It has been found advisable to devocalize all animals upon the day of entry into the laboratory.

2. During experimental work the subject is isolated in a soundproofed room where he can be observed through one-way-vision windows.

3. Flexion reactions are recorded by a special pneumatic system described in detail.

4. Methods of recording conditioned responses of the muscles by the oscillographic technique have been developed.

5. By combining the automatic recording devices it has been possible to obtain as many as 6 simultaneous records from a single subject. These include the movements of all 4 feet, the tensions of a particular muscle group, and the respiration.

6. Devices for measuring the different kinds of experimental records and refinements in habituating and training the animal subjects have also been discussed.

(Manuscript received September 17, 1938)

THE SIMULTANEOUS TRANSFER OF CONDITIONED EXCITATION AND CONDITIONED INHIBITION [1]

BY DELOS D. WICKENS

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In a previous study (4) the writer demonstrated that conditioned excitation and conditioned inhibition could be transferred separately from one muscle group to the antagonist. In that experiment an extensor movement of the finger was conditioned to a buzzer with shock as the unconditioned stimulus. Following this, the hand was turned over so that a flexor movement must be made to remove the finger from the electrode, and the buzzer was sounded. Ten out of the 18 subjects immediately responded by making flexor movements in this new situation, while the remainder made this type of movement after only a very few reinforcements. In a second part of the experiment the extensor response was developed, and the transferred flexor response was extinguished. Then the hand was turned back to the original position, and the buzzer was sounded to test for the presence of the extensor response. It was found that the flexor extinguishing served either to inhibit the extensor response completely, or to depress it considerably. In the present experiment this general procedure was carried a step further and an investigation was made to determine whether or not conditioned excitation and conditioned inhibition could be transferred simultaneously.

Apparatus

The apparatus used was the same as in the previous study. It consisted of a conditioning board with the usual straps and arm blocks, the finger electrode being placed on a spring platform so that either upward or downward movements of the finger which were greater in magnitude than $\frac{1}{16}$ inch could be recorded on the polygraph. A high frequency buzzer was the excitatory stimulus; a bell was the inhibitory stimulus.

[1] This work was done at the University of North Carolina during the summer of 1937.

The shock was delivered by a Harvard inductorium. The subject and the experimenter were in adjoining rooms which were connected by a door.

Procedure

After the subjects, all of whom were students in the elementary course in Psychology, had been strapped into the apparatus with the palm down, those who had no knowledge of conditioning (naive subjects) were given the following directions:

> "During this experiment you will be given a shock periodically and there will be other things going along at the same time, but right now we want to adjust the shock and make it strong enough so that you'll lift your finger up without thinking much about it. During the experiment I want you to maintain something of a passive attitude. You should, of course, know what's going on all the time, but in general just sit back and take it easy."

If the subjects had already some knowledge of the CR, the directions were modified and given in the following form:

> "This is a conditioning experiment, and you will be given a shock and a buzzer together. Right now we want to adjust the shock and made it strong enough so that you'll lift your finger without thinking much about it. During the experiment, I want you to maintain something of a passive attitude, and if you feel yourself becoming conditioned do not fight against it. At the same time do not respond voluntarily. Remember what's going on, but just sit back and take it easy."

Then the shock was stepped up until the subject gave a quick vigorous response and indicated that the shock was as strong as he was willing to take. After the usual tests for responses to the buzzer and bell alone were made, the sound of the buzzer was paired with the shock. These paired stimulations were given by hand, with the buzzer preceding the shock by a short interval. Paired presentations at irregular time intervals were given until the experimenter observed by means of lights in parallel with the response circuit that the subject was consistently anticipating the shock. At this point the bell alone was sounded, and as all subjects responded to it, the process of differentiation was begun, the bell alone, and the buzzer plus the shock being presented irregularly. After the differentiation had become sufficiently stable so that the S was consistently failing to respond to the bell, and was equally consistently anticipating the buzzer, the experimenter entered the subject's room and turned the subject's hand over. In this new position the palm was up so that a flexor rather than an extensor movement had to be made in order to remove the finger from the electrode.

Then the test for transference was made, the buzzer (which in this case was never accompanied by a shock) and the bell being presented ten times, each according to a prearranged chance order. Two different orders were used, the one being the opposite of the other. Thus, one series began in the order, buzzer—bell—bell—buzzer, and the other in the order, bell—buzzer—buzzer—bell. With three of the subjects one order of presentation was used, and the other order was used with the remaining four who completed the experiment. With the exception of the first two S's, the time intervals between stimulations were constant. These varied between five and twelve seconds.

Each experimental session was about one hour in length with about 160 stimulations per session, and the subjects came for as many sessions as necessary. The greatest number of sittings required was five, and the least was three. Three additional subjects were used but for various reasons the experiment had to be terminated before the desired criterion of differentiation was reached; therefore, their results are not included. One subject sat for two sessions, another three, and a third for four. Except

for the first S, all of them were showing evidence of discrimination when the experiment was terminated.

Results

The results of the experiment are given in Table I. The column following the subject's identification indicates whether the subject was familiar or unfamiliar with conditioning and its various phenomena, while the third column gives the number of experimental sessions in which each subject participated in order to complete the experiment. Columns four and five are the ones of greatest interest for this experiment, since they are records of the behavior of the subject in the new palm up or flexor response position. Column four

TABLE I

Showing the Subject's Knowledge or Ignorance of Conditioning, the Number of Sessions Necessary for Differentiation, and the Number of Responses to the Positive and Negative Stimulus in the Flexor Response Position

Subject	Subject's Attitude	Total Number Experimental Sessions	Behavior in Palm up Position	
			Response to Buzzer	Response to Bell
Bu	Naive	5	10	1
Lo	Sophisticated	3	10	0
Jo	Naive	4	3	0
Bl	Naive	3	2	0
Co	Naive	3	7	0
Bla	Naive	4	4	0
Je	Sophisticated	3	9	1

indicates the number of flexor responses to the buzzer or positive stimulus, out of ten stimulations, and column five indicates the number of flexor responses to the bell or negative stimulus out of the same number of stimulations. Thus, to read the table for the first subject, Bu had no knowledge of conditioning and attended five sessions before the experiment was completed. In the palm up position he responded with a flexor movement of the finger each of the ten times the buzzer was sounded, and made one flexor response to the bell.[2] The

[2] The experimenter would interpret this one response to the bell as an incidence of temporary disinhibition of the negative response to the bell, this disinhibition resulting from the stimulation involved in turning the hand over or the unaccustomed tactual stimulation caused by placing the arm in a new situation. This interpretation is made solely on logical grounds and may, of course, not be valid experimentally.

description of the behavior of the other subjects is read in a like manner, and it is easily seen that their actions are essentially the same as those of the first subject. All of them show that there is a simultaneous transference of both conditioned inhibition and conditioned excitation from one muscle group to the antagonist. Thus, these results are in accord with those of the experiment previously referred to and could very easily be predicted from that experiment.

In view of the one exceptional case in the previous experiment, who continually made extensor rather than flexor movements in the palm up position, subject Je of this study is of particular interest. Three of the times that the buzzer was sounded he made an extensor or downward movement and then, while the buzzer was still sounding, made a flexor movement. After the experiment, he mentioned this to the experimenter without solicitation, saying that a funny thing happened when the buzzer sounded the first few times. First, the finger went down as far as it would go. (The downward excursion of the platform was limited by its electrical contacts which were connected with the polygraph) and then it flew up. No verbalization accompanied this behavior; the finger just acted that way of itself. Nor could the subject explain why these initial extensor movements were eliminated after the third buzzer stimulation; it just happened that way. In response to the question as to why he made a flexor response when the bell sounded the first time, he stated that he thought he did this because, in the process of differentiation during the palm down situation, he made a flexor movement whenever the bell was rung.[3] This subject, then, is an exception to an intermediate degree. With him, although the directions of finger movement which were conditioned in the palm down position still persist during the first few stimulations in the palm up position, they are immediately corrected—if making what is logically a more adaptive movement in this situation may be called correcting—and are very rapidly eliminated.

[3] Since, to some extent at least, differentiation and experimental extinction are similar, this incidental finding lends further support to Wendt's theory which holds that the process of experimental extinction consists of the development of an antagonistic response (3).

Unlike the more typical subjects, he does not immediately make the most adaptive movements in the new situation, and, unlike the exception of the first experiment, he does not continue to make these less adaptive movements until experimental extinction sets in.

Discussion

The theoretical significance of these experiments has already been discussed in the previous article, and it is only necessary to reemphasize the point that this work stresses the functional nature of the conditioned response as opposed to its muscular nature. Something of a satisfactory explanation of the results of the two experiments may be attempted by combining the facts of conditioning with the phenomenon of set. An approach of this sort has already been made by Gibson, Jack, and Raffel (1) in an explanation of a similar problem in which they found a transference of a conditioned response from the finger of one hand to the same finger of the contralateral hand, but the writer had objected to it in his earlier work because it seemed too general in nature.[4] A similar view has also been taken by Hilgard and Humphreys (2) who found that attitudes voluntarily assumed by the subject do "participate in conditioned discrimination, but they do not suffice to account for the whole process" (2, p. 302). The author would consider the mechanisms involved in conditioning, and the phenomenon of set as two independent factors, the latter of which may be used to influence the former. Thus, the subject is conditioned—there is an excitatory value attached to the sound of the buzzer, a value which demands that the organism make a response to the stimulus; similarly, an inhibitory response is attached to the sound of the bell. Ordinarily, the direction and the nature of the muscular movement involved in these responses will remain as it was determined by the objective situation in which the connection was first established, but this need not

[4] In a conversation Dr. Gibson expressed the opinion that he had not intended the explanation to be as general as it was interpreted, so it is possible that the views to be presented are only a more specific reformulation of his theory.

always be true. When the subject is placed in a different situation, his perception of the nature of the situation results in a postural response or set which may be different from the postural response originally present. Now, when the excitatory stimulus occurs, a phasic response must be made, and the kind of phasic response which is made is determined by the set at the instant the stimulus occurs. In like manner, an inhibitory response is made to the negative stimulus. This does not mean that set necessarily has anything to do with the original establishment of an excitatory bond between the buzzer and making some kind of response, but only that the type of phasic response which will be made can be modified by the organism's set.

Such a theory would, of course, fit the facts of this experiment, but it must not be taken as an attempt to explain conditioning.

So far as the nature of conditioning is concerned, this experiment, along with that of Gibson, Jack, and Raffel, indicates that it is erroneous to assume, at least for certain kinds of conditioning, that, because a certain muscular response or responses happens to occur along with the presentation of the incidental stimulus, it is this response alone which is conditioned. It would appear that, with the conditioning of this response, there is also being 'latently' conditioned other responses which, in a modified situation—hence altered postural response—, might become the equivalent of this response. If this be true, then one of the problems of conditioning would be to determine what other responses are the equivalent of the one which is originally paired with the incidental stimulus. It is only by this means that we could determine all that has been conditioned. Thus, if we couple the results of this experiment with those of Gibson, Jack, and Raffel, we learn that when an incidental stimulus is paired with an electrical shock delivered to the finger of one hand, we have conditioned not only withdrawal movement in a certain direction of this particular member, but the following other responses which a different situation make the equivalent of it: namely, a similar type of withdrawal movement of the op-

posite hand, and also the antagonistic movement of the same finger. What else we have conditioned is now an experimental rather than a theoretical problem, and further experimental work studying the transference to other parts of the body would permit us to determine how general or specific our conclusion should be.

Summary

As a follow-up of a previous study, an extensor movement of the finger of the right hand was conditioned to a buzzer, shock being the unconditioned stimulus. Then a differential response between the buzzer and a bell was established. Following this, the arm was turned over, making the movement necessary to remove the finger from the electrode a flexor one.

(1) The results indicate that there is a simultaneous transference of conditioned excitation and also conditioned inhibition from one muscle group to its antagonist.

(2) An interpretation of the results is made in terms of the facts of conditioning and the phenomenon of set.

(Manuscript received September 22, 1938)

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LENGTH OF THE PRACTICE PERIOD AND EFFICIENCY IN MOTOR LEARNING *

BY ROLAND C. TRAVIS

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Introduction

Recent studies on the effect of spaced and unspaced practice periods in motor learning by several independent investigators showed a general similarity in results. The best results are obtained when the distribution of practice and rest periods lie somewhere between an overcrowding which disrupts learning and a long separation of practice periods which allows a loss of previous gains.

Several different methods have been used in studying the effect of the length of practice and rest periods on motor learning. Notable among these are studies using the Koerth pursuit rotor, the Renshaw pursuitmeter and the manual pursuit-oscillator with a systematic variation of the distribution of practice and rest periods.

The purposes of this report are: first, to revaluate some experimental results of two previous studies by the author (1, 2), second, to present some new experimental results on the effect of the length of the practice period with the length of the rest period constant, and third, to present an interpretation arising out of recent work in this special field.

Revaluation of Former Results

Previous research (1) by the author on the effect of the length of the rest period on learning in eye-hand coördination indicated that rest periods of 20 minutes between practice periods were more efficacious to learning than rest periods of 5 minutes or much longer periods of 48 hours, wherein the length of the practice period remained constant at 5 minutes. In other words, rest periods of 5 minutes were too short and

* The author gratefully acknowledges the assistance of Mr. Harold Wyandt.

rest periods of 48 hours were too long for most effective learning, with a practice period of 5 minutes. In a more recent study by the author (**2**) using the same experimental technique and the manual pursuit-oscillator, the practice periods were restricted to 1 minute in length and the rest periods 3 minutes in length. Comparing the results of these two studies several outstanding differences were noted, as will be seen from an inspection of Table 1 and Fig. 1. Three curves are presented

TABLE 1

AVERAGE PERCENTAGE SCORES FOR SIX TRIALS FOR THREE GROUPS OF COLLEGE MEN WITH PRACTICE AND REST PERIODS VARYING IN LENGTH WITH THE MANUAL PURSUIT-OSCILLATOR

Trials	Group-1 (17 Sub.). One Min. Practice. Three Min. Rest	Group-2 (10 Sub.). Five Min. Practice. Five Min. Rest	Group-3 (10 Sub.). Five Min. Practice. Twenty Min. Rest
1	52	18	18
2	62	37	38
3	72	46	56
4	78	57	68
5	80	64	78
6	82	70	87
Total gain	30	52	69
Total amount of practice minutes	6	30	30

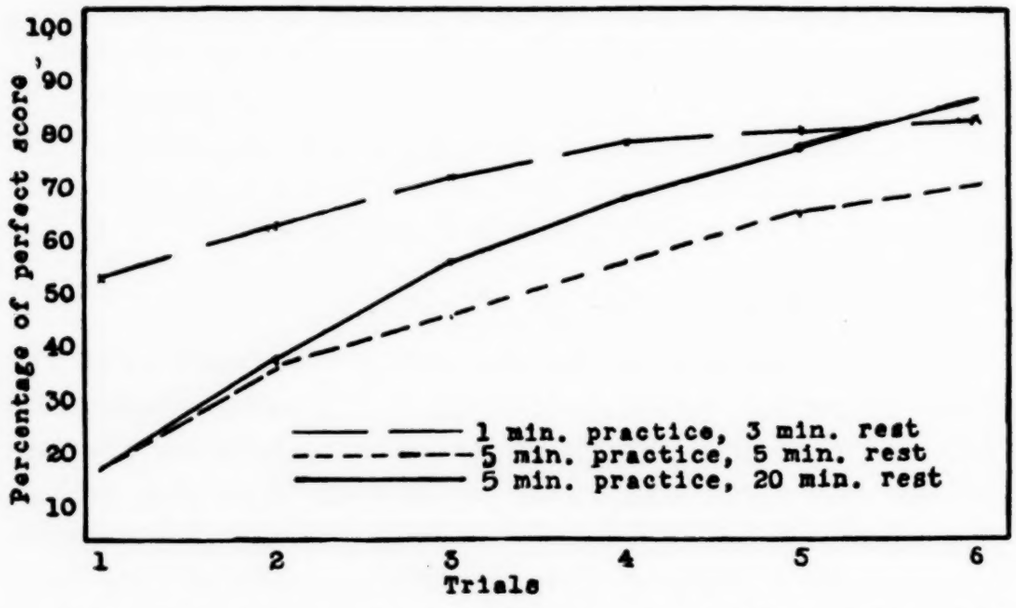

FIG. 1. Learning curves for three different groups of college men in eye-hand coördination using rest and work periods of different lengths.

with three different groups of subjects (college men). For group-1 the practice periods were 1 minute in length with rest periods of 3 minutes. For group-2 practice periods of 5 minutes and rest periods of 5 minutes were employed. For group-3 practice periods of 5 minutes and rest periods of 20 minutes were used.

Comparing the three groups we found that the group which practiced one minute and rested 3 minutes had a significantly higher initial score than the other two groups. The group which practiced 5 minutes and rested twenty minutes had a higher final score and a significantly greater total gain than the other groups. A pertinent observation from these results would be that the length of the practice periods and the length of the inter-practice rests are fundamentally related. That is the longer the work period the longer the rest period must be for most effective learning within certain limits. Furthermore, in learning of this type, practice periods longer than a certain length are extremely deleterious to learning in the early trials.

Effect of Varying the Length of the Practice Period with Length of Interpractice rests Constant

Using three groups of college men and a modification of the manual pursuit-oscillator the length of the practice periods were varied in length (One minute, 2 minutes and four minutes) with the length of the inter-practice rests constant at 3 minutes.

The pursuit-oscillator was modified so that the task of the subject was quite different from that of the earlier arrangement (3). The task of the subject in the present setup was to hold a stylus (gravity type, hinged in center) on a small silver target (13 cm in diameter), this closed a relay which started the motor and moved the platform which carried the target. As soon as the target moved, the stylus lost contact with the target thus the current was cut off from the motor and the platform stopped. The subject again contacted the target with the stylus and the platform moved again. This process of starting and stopping the platform continued until the subject's skill had increased to the point where he could remain on the target for several complete oscillations of the platform. Lapses in attention and minor muscular incoördinations prevented any subject from making a perfect score in any trial even after many trials and days of practice. The platform was mounted 46 cm from its center of rotation and oscillated through an arc of 13 degrees at the rate of one complete oscillation in one second when the motor ran continuously.

The electric relay was the micro-switch type made by the G-M Laboratories Inc. and was found to be very satisfactory for quick starting and stopping of the motor and it possessed remarkable durability. A Veeder counter connected directly to the reducing gear recorded the number of oscillations of the platform.

An inspection of the results shown in Table 2 and Fig. 2 shows that small insignificant differences were found between all three situations using practice periods of different lengths with the length of the rest periods constant. Ranked in order of percentage scores they are: first, the two-minute

TABLE 2

AVERAGE PERCENTAGE SCORES FOR THREE DIFFERENT GROUPS OF COLLEGE MEN (18, 17 AND 17 SUBJECTS RESPECTIVELY) IN EYE-HAND CO-ORDINATION FOR 6 TRIALS WITH PRACTICE PERIODS OF ONE MINUTE, 2 MINUTES AND 4 MINUTES. INTER-PRACTICE RESTS CONSTANT AT 3 MINUTES

Trials	Group-1 (18 Sub.). One Min. Practice	Group-2 (17 Sub.). Two Min. Practice	Group-3 (17 Sub.). Four Min. Practice
1	69.3	72	69
2	75	76.8	72.8
3	77.7	79.8	76.6
4	80	80.7	78
5	79.8	83	81.5
6	81.3	84.6	82.1
Total ave.	77.3	79.5	76.3
S. D.	11.4	7.6	8.4
C.R.	(1 and 2) 1.7	(1 and 3) 0.7	(2 and 3) 2.9
Total practice minutes	6	12	24

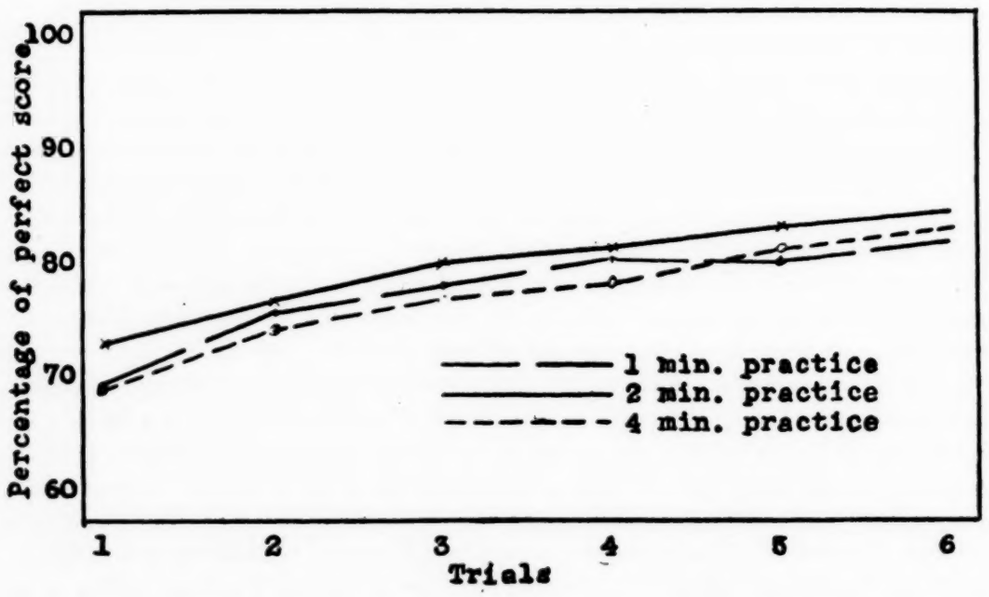

FIG. 2. Learning curves for three different groups of college men with work periods of one minute, 2 minutes and three minutes respectively, with the inter-practice rests constant at 3 minutes. Eye-hand coördination on the manual pursuit-oscillator.

practice period; second, the one-minute practice period; and third, the four-minute practice period. Two of the three critical ratios are too low to be of statistical significance. The critical ratio of 2.9 between the two-minute and the four-minute practice periods points towards a definite inferiority of the longer practice periods. These data indicate that it is better to have the practice periods short (*e.g.*, one minute) than long (*e.g.*, four minutes) if the inter-practice rests are relatively short (*e.g.*, three minutes).

Another significant point should be mentioned here in connection with the total amount of practice. The total amounts of practice for groups 1, 2 and 3 were 6 minutes, 12 minutes and 24 minutes respectively. Group-3 which received the greatest amount of practice (24 minutes) had the lowest percentage score despite the fact that the total practice was 4 times that for group-1 (6 minutes). It would seem reasonable to state since group-2 received the highest score with a total practice of 12 minutes that at least the latter half of each practice period for group-3 was a sheer waste of time and actually deleterious to learning of this type.

Discussion and Interpretation

Since most effective motor learning takes place by alternating rest and practice periods of certain lengths and since the relative lengths of rest and practice periods seem to be fundamentally related and interdependent, it seems reasonable that we are dealing with an aspect of the general 'rhythm' or 'periodicity' of activity of the organism. Organic rhythms and periodicities in activities are well known to the physiologist. For example, the refractory phase of the heart beat, nerve conduction, reflex conduction as discovered by Kronecker and Stirling, Broca and Richet, Verworn, Zwaardemaker, Gotch and Burch, Lucas, Sherrington and others. General observations on human activities that work must be followed by rest and rest followed by work point definitely towards an hypothesis which includes 'organic periodicity' in activity as an essential characteristic of not only physiological functions but psychological processes as well.

Apropos of the refractory phase as being one aspect of this general 'organic periodicity' several studies may be cited. Dodge (4) found in his studies on the knee-jerk and the lid-reflex that the repetition of stimuli may have an opposite effect to that commonly referred to as learning. That is, an antecedent stimulus may raise a barrier to repetition within a sufficiently short interval of time and the response to the second stimulus shows a decrement. This decrement indicates that the reacting tissue is relatively insensitive to that particular stimulus for a measurable time interval. The length of this time interval (refractory phase) varies with the complexity of the neuro-muscular system involved. The refractory phase is in the order of a few thousandths of a second in nerve fibers, one-half second in the knee-jerk, three seconds or more in the lid-reflex and still longer in more complex systems. The author (5) found in presenting visual stimuli the intensity of which was near the threshold under dark adaptation conditions that a phenomenon similar to refractory phase was demonstrable. The lower the intensity of the stimulus the greater the time interval between stimuli in order to arouse a visual response.

In recent studies with the pursuitmeter Renshaw and Schwarzbek (6) found that, "the length and distribution of the intercyclic rest periods have great effect on the shape of the practice curve. When all other conditions of learning are constant, this factor alone may be as effective in transforming the shape of the curve as motivation or the length, number or frequency of the practice periods."

Doré and Hilgard (7) using the Koerth pursuit rotor obtained results similar to those described in the present report. They advocate the stimulation-maturation hypothesis as a probable interpretation of this phenomenon. They state, . . . "distributed stimulation in a specific function will give rise to an improvement in that function at a rate which is related more closely to the time elapsing from the beginning of practice than with the total amount of practice." In other words, learning is a time-function rather than a practice-function. Doré and Hilgard followed the lead of Wheeler (8)

and referred to this time-function as one type of maturation in the sense that stimulation does something to the reacting tissue and time alone will make it ready for another stimulation of the same order. This time-function, of course, is the essential characteristic of *pacing*, and pacing is distributing stimulation in accordance with the fundamental refractory phase or activity-rhythm of the particular neuro-muscular system involved. The term 'maturation' is used in this connection with doubtful justification. On the other hand, the refractory phase hypothesis is descriptive and is an attempt to describe what is actually happening to this periodic breaking-down and recovery of reacting neuro-muscular systems.

It seems reasonable that the refractory phase hypothesis comes closer than other hypotheses in explaining the necessity of a certain distribution in time of practice and rest periods for greatest effectiveness in motor learning.

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